AD 612290

Report No. RD-64-134

INTERIM REPORT

Project No. 430-202-02R

ANALYSIS OF APPROACH LIGHTING CONFIGURATIONS FOR VISUAL TRANSITION UNDER CATEGORY II OPERATING CONDITIONS

FEDERAL AVIATION AGENCY ★ UNITED STATES OF AMERICA ★

SEPTEMBER 1964

FEDERAL AVIATION AGENCY
Systems Research & Development Service
Atlantic City, New Jersey

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September 1964

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ABSTRACT

Three experiments were conducted to determine requirements for modification of the present U. S. National Standard Approach Lighting System (Configuration A) to meet Category II visibility operating requirements (1, 200-foot Runway Visual Range). A building blocks approach was used in which each increment in configuration complexity had to be justified on the basis of a demonstrated gain in performance while the pilot is being systematically exercised in the utilization of the system. The experiments were conducted in a visual landing simulator. The results indicate that satisfactory performance of visual transition for landing can be achieved with a basic center row and crossbar configuration, including sequence flashing lights operated to the point of acquisition of the steady burning light components of the system.

INTRODUCTION

In the development of an approach lighting system suitable for support of operations under Category II (maximum Runway Visual Range (RVR) 1,200 feet) visibility conditions, it is essential to give the pilot the information he requires for visual transition and landing with a minimum of interpretive effort. High rates of closure and the brief time available to perform such corrective maneuvers as are feasible under these operating conditions do not grant the pilot the opportunity to segregate signal from noise. The visual system must be functional in every detail. Pattern elements that do not contribute to the information or guidance functions of the display, or may add without purpose to its installation or operating costs, must be avoided.

The purpose of the simulator experiments described in this report is to make a preliminary determination of which features of approach lighting configurations contribute positively to the guidance value of these systems. What is an adequate approach lighting configuration for visual ranges in the vicinity of 1,200 feet, insofar as it can be determined in the visual landing simulator?

In order to approach this question in an orderly and systematic manner, the experiments are laid out in a building blocks framework in which the first block is an elementary interpretation of the system concept and each subsequent block in the series represents a single increment in complexity that may or may not add to the guidance value of the whole. The results of these experiments should enable us to ensure that each pattern element included in the total configuration has been justified by a demonstrated increase in the rate at which the pilots utilizing the configuration reach a level of performance judged to be adequate for safe and expeditious execution of the approach and landing maneuver.

The pattern concept selected for study in this program is a minimum departure from the present center row and crossbar arrangement of the U. S. Standard Configuration A (see Figure 2*). Since Configuration A is based on the extended runway centerline, the first level in the building blocks series is a single line of lights at 100-foot intervals, extending 3,000 feet out from the runway threshold (Figure 1, Level 1). This minimum array should provide directional guidance

*In order that the reader might have the configuration drawings in view, while following the text, Figures 1, 2, and 3 are printed on fold-out pages appearing in Appendix F.

and some degree of attitude and rate of descent information, although roll guidance would be largely lacking and confusion with runway centerline lighting quite possible. In the second block of the series, roll guidance would be partially restored, and the probability of confusing the center row approach lighting with runway centerline lights would be somewhat reduced, by expanding the single light center row into the 14-foot barrettes used in Configuration A (Figure 1, Level 2). In the third block, the basic configuration of the National Standard has been further restored by the addition of the 1,000-foot crossbar called the Decision Bar in Configuration A because it serves as a warning that if runway threshold lights are not in view at this point, consideration should be given to executing a missed approach. The major guidance element added to the system, of course, is distance to threshold information. Also, the decision bar adds very strongly to the horizontal orientation of the system—it is sometimes called the roll bar—and attitude and rate of descent information are facilitated by the large visual angle that it subtends with the runway threshold. This configuration differs from Configuration A only in that the red termination bar and wing bars have been deleted and the center row of barrettes has been extended to the runway threshold (Figure 2). Recommendations for simplifying modifications of Configuration A along these lines have been made before (Reference 11).

The next block in the series adds side rows of lights between the decision bar and the runway threshold (Figure 1, Level 4). The primary purpose of these side rows is to improve roll and cross-track guidance in the basic configuration. Proponents of this step feel that the pilot will be aided in observing drift tracking errors by the added contrast in pattern between the center row and side rows, enabling him to more easily detect when the ground track is not congruent with the centerline. In United Kingdom and Netherlands versions of this pattern, the side rows are barrettes and the center row a single line of lights, more or less a mirror image of the pattern described here. Because this treatment results in a similarity of pattern between the last 1,000 feet of approach lighting and the touchdown zone lighting, the side rows in the approach lighting segment are red. Reversal of the pattern elements of the configuration used in this experiment accomplishes the same purpose without requiring the application of color.

In Level 5 an additional side row is added to the left in the last 1,000 feet to increase the detectability of cross-track error, and thus the directional guidance quality of the system. The six-block series is completed by the addition of a second crossbar 500 feet from the threshold (Level 6). With this extra crossbar the pilot has additional information on distance to threshold and, presumably, a more adequate basis on which to set aside or implement an abort decision. The

additional crossbar should, in general, strengthen the ground plane impression provided by the configuration.

All the developments beyond Level 3 have been proposed as means for packing more information in the last 1,000 feet of the approach lighting configuration so that it can more adequately support operations where visual transition is attempted at an altitude of less than 200 feet, and a slant visual range of 1,200 feet. Whether, in reality, the information and guidance value of the system is enhanced or degraded by this added complexity is the question to which Experiment I in this series is addressed. Experiment II subjects the basic center row and crossbar configuration (Figure 1, Level 3, and Figure 2) to more extended analysis, particularly as to whether it could become quite adequate and better accepted if the pilots were thoroughly trained in its use. Finally, Experiment III investigates the guidance value of sequence flashing lights and attempts to provide a better perspective for their use in combination with, or separate from, steady burning lights (Figure 3). In this manner it is believed that most of the basic questions involved in adaptation of the U. S. National Standard Configuration A Approach Lighting System to Category II operating visual ranges are considered.

EXPERIMENT I

Experimental Method

The plan of the experiment (Table I) is based on a three by five factorial design in which there are repeated measures on one factor, in this case "axis of displacement." Complexity of the approach lighting pattern is graduated in six levels, as described in the previous section. On this dimension, the experiment was replicated 5 times, i.e., there were 5 subjects in each level for a total of 30 for the experiment. Nineteen subjects were drawn from the operational pilot population at NAFEC, 11 from the casual pilot population. Nearly all had extensive instrument and multi-engine experience, and the majority of the casual pilots had military experience. Assignments to levels were random within the limits of pilot availability.

All pilot subjects were given sufficient flight familiarization in the simulator to achieve a satisfactory degree of proficiency as judged by the experimenter, who was a qualified pilot and simulator instructor, with the concurrence of the pilot himself. In a "pre-test" briefing, each subject was advised that he was participating in research directed toward the effectiveness of several modified versions of the Standard Configuration A Approach Lighting System. He was further informed that he would fly full instrument landing system (ILS) approaches with a localizer course of 360° for landing on "Runway 36."

On the initial take-off for each session, the pilot flew the simulator to 1,500 feet and maintained a heading of 360°, when the experimenter activated the radio aids and manually positioned the flight approximately one mile beyond the outer marker (OM), 6.2 miles from the runway threshold. At this point, the pilot was released to start the approach. Interception of the 2.6° glide slope occurred at 1,500 feet. Visual breakout occurred at 200 feet altitude and 1,200 feet slant range to the first detected approach light. The letdown procedure involved landing gear extended, 30° flaps, and power setting of 19" manifold pressure with 2,100 RPM, resulting in an air speed of 130 knots on a 500-600 fpm rate of descent.

In their briefing the subjects were told that on all approaches the experimenter would inject a condition in the flight simulator that would produce a displacement about some axis of flight. When this condition was detected after going visual, they were expected to execute the appropriate corrective maneuver with reference to the visual cues presented by the configuration, so as to bring about an optimal alignment

TABLE I

Experimental Design (Experiment I)

Independent Variables

Level of Complexity (6 levels)
Axis of Displacement (3 axes)

Dependent Variables

Displacement recognition
Rate of execution of the corrective maneuver
Rate of closure, or flare path
Longitudinal positioning at touchdown, precision of
Lateral positioning at touchdown, precision of

3 x 5 Factorial and Number of Subjects or Replications

	Level of Complexity						
Axis of Displacement	1	2	3	4	5	6	Σ
(H) Heading							
(A) Attitude	5	5	5	5	5	5	30
(D) Track							

Number of Trials per Subject per Level of Complexity

	Level of Complexity						
Axis of Displacement	1	2	3	4	5	6	Σ
(H) Heading	9	9	9	9	9	9	54
(A) Attitude	9	9	9	9	9	9	54
(D) Track	9	9	9	9	9	9	54
Σ	27	27	27	27	27	27	162

Schedule

Session	No. of Trials	Variable Sequence
1	9	H, A, D in random order except to
2	9	stop runs and equalize total number
3	9	under each condition.

and attitude for landing. Transition to visual flight occurred after passing the middle marker (MM), usually about 200 feet in altitude. After touchdown and landing roll out, the pilot was manually repositioned beyond the OM at the specified heading and altitude for another approach. Each subject flew a series of 3 sessions consisting of 9 approaches per session, a total of 27 approaches per pilot and 810 for the experiment.

The flight procedure utilized in this experiment is very similar to the procedure followed on a number of other occasions in simulator studies of airport marking and lighting systems (References 6-12). Through controlled manipulation of the simulator flight environment, rotational or track displacements are introduced on each axis of flight on that part of the flight path where the visual system is supposed to provide guidance information, and the pilots' ability to recognize these displacements, and to control visually the rate at which they are corrected, is analyzed. In this approach lighting problem, the displacements introduced were in pitch or attitude (A) with respect to glide path; heading (H) with respect to line of flight (wind correction); and track (D) with respect to the extended runway centerline. The underlying assumption is that the pilot is performing a compensatory tracking task in which the comparison stimulus is the visual recall of the appearance of the scene when the approach is being performed correctly. The pilot must remember how things appear when the flight is proceeding satisfactorily and interpret the ongoing visual scene accordingly. In utilizing the visual system, the pilot should be influenced in the frequency with which he reaches criterion levels of performance by the clarity with which relevant cues are provided. Level of performance was determined by the experimenter's observation of the pilot's actions and the correlated changes in the visual scene, and by recording of flight path and touchdown point. Scoring categories included:

1. (H) Heading correction (maneuver identification). Rotate or de-crab to the desired track or the same heading as the runway when cross wind is removed.

2. (A) Attitude (pitch) correction (maneuver identification). Rotate or correct attitude and rate of descent to maintain glide or flight path with projected impact at the ILS reference point.

3. (D) Displacement correction. Cross-track correction from a lateral displacement, resulting in alignment with centerline.

4. Rate of maneuver execution. Recorded as completed or not completed prior to crossing threshold.

The equipment used in the experiment was the P-3 Flight Duplicator which approximates the characteristics of a 25,000 lb. twin engine B-25 class aircraft and the Dalto Moving Belt Visual Simulator Attachment.

Additional details of the experimental procedure and the simulation equipment appear in Appendixes A and B.

Statistical Method

The method of analysis is described by Winer (Reference 16) as a two-factor experiment with repeated measures on one factor. The form of the analysis is shown in the tables in Appendix C. As can be seen by inspection of these tables, where independent sampling is utilized, as on the levels of complexity dimension, the appropriate error term is the "within subjects" variance. When repeated measures on the same subjects are used, as on the "axis of displacement" dimension, the appropriate error term is the axis by subjects by within groups interaction.

Since a test of homogeneity of variance indicated possible lack of homogeneity in the cell variances for displacement recognition scores, all scores based on proportion were normalized by an arcsin transformation. The arcsin transformation is appropriate for scores greater than "0" but equal to or less than one. In this experiment, each subject had nine opportunities to detect the axis of displacement, or otherwise to reach criterion levels of performance. His score could range, therefore, from 0-9, which converted to a scale of .1-1.0 for the arcsin transformation.

Performance Results

The results of the analysis of variance show in general that the differences in pilot performance that can be attributed to differences in the level of complexity of the lighting pattern are very limited. In fact, the effect of all of this elaborate attempt to manipulate the quality and content of information provided by the last 1,000 feet of approach lighting produced only one effect attributable to this factor, and this effect can be interpreted only in consideration of the axis of displacement involved. The measure is the axis by levels interaction in ability to complete (execute) the corrective maneuver before crossing the threshold (Table II, Line f). What this interaction means can be surmised to some degree by inspection of Figure 4f. With the addition of the 1,000-foot crossbar in Level 3, ability to control attitude (i.e., vertical path) corrections improves as much as it is going to, and is degraded by the reduction in

TABLE II

Performance Measures on Which Probabilities of .10 or Better Were Obtained

Measure	Source of Variation	F	df	p
a. Recognition	Axis of Displacement	7.14	2/28	.01
b. Optimal Flare Path	Axes	2.840	2/28	.10
c. High Flare Path	Axes	3.478	2/28	.05
d. Lateral Pos. Within TDZ	Axes	3.653	2/28	.05
e. Longitudinal Pos. Short	Axes	2.546	2/28	.10
f. Execution Before Threshold	Axis x Levels	1.876	10/28	.10

primary visual angles subtended when the extra crossbar is added at 500 feet (Figure 4f, Level 6). On the other hand, there is a tendency for added complexity in lateral elements of the pattern merely to degrade execution of track or heading realignment maneuvers, again up to Level 6. This last quirk in the performance profile the authors cannot pretend to explain, unless Level 6 subjects were unusually competent. Other data (Figure 5) show execution of the corrective maneuver to be a more difficult task than recognition of the requirement for a corrective response. That a single row of lights is quite adequate for longitudinal alignment is, however, quite consistent with the results of analyses of similar requirements for helicopter approaches (Reference 15).

Otherwise, the source for performance differences is axis of displacement. Analysis of variance results on this dimension are summarized in Table II a-e, and illustrated in Figure 4 a-e. As has been noted in a previous report (Reference 11), recognition is most difficult for attitude displacements (Table IIa and Figure 4a). Achievement of optimal flare path is also most difficult in the case of attitude displacement, a result not unexpected when it is considered that introduction of this variable deliberately forces the pilot high on glide path (Table IIb and Figure 4b). The same point is made, of course, by the finding that pilots most often level off high on runs involving attitude displacement (Table IIc and Figure 4c) and that they least often land short (Table IIe and Figure 4e) on these runs. It would be expected similarly that experimentally introduced lateral or heading displacements would depress the frequency with which lateral positioning at touchdown occurs inside the touchdown zone lights (Table IId and Figure 4d). All in all, these results offer excellent independent confirmation of the success of the experimenter in achieving effective and meaningful displacements about the axis or line of flight.

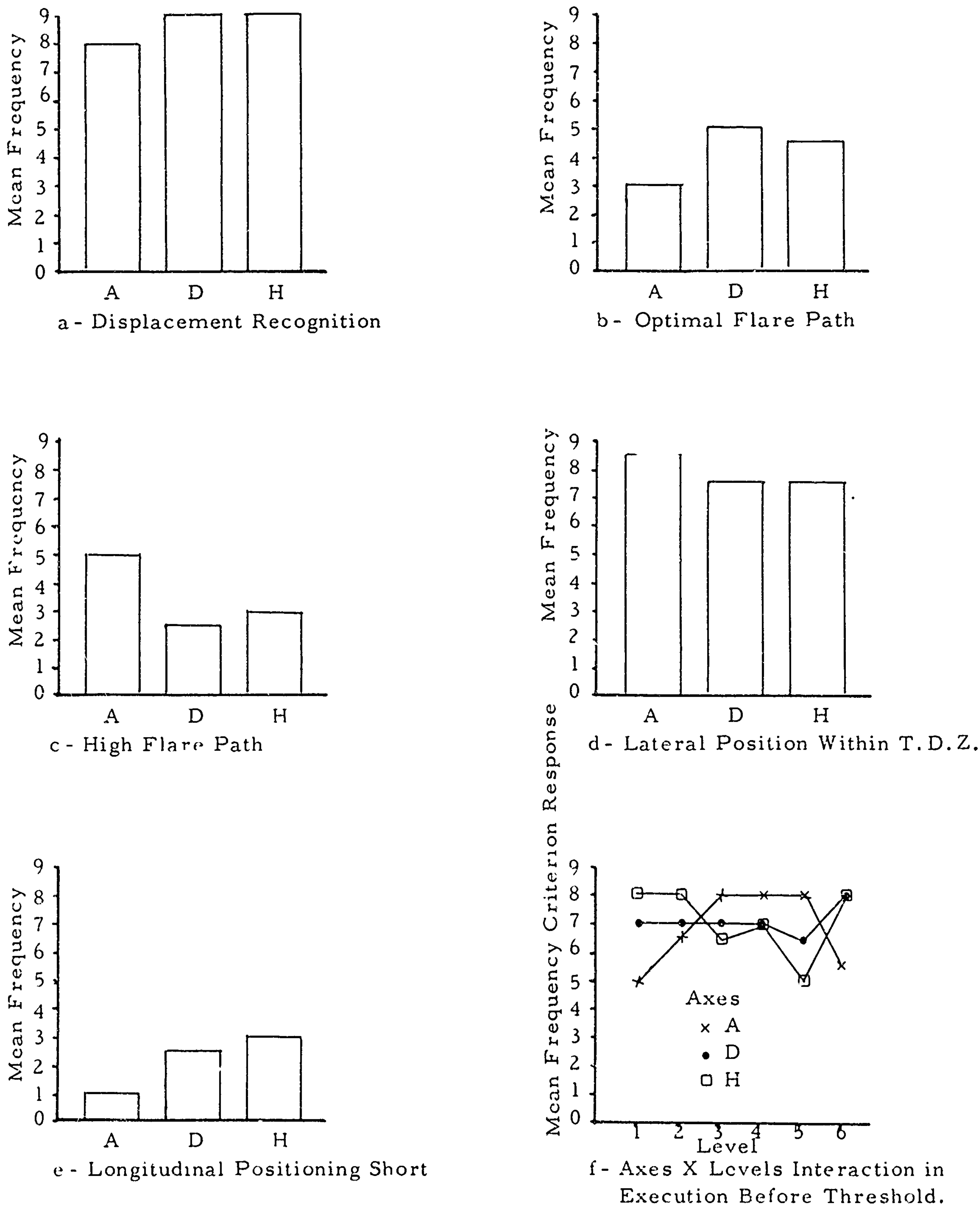

FIG. 4 DISPLACEMENT PERFORMANCE EFFECTS.

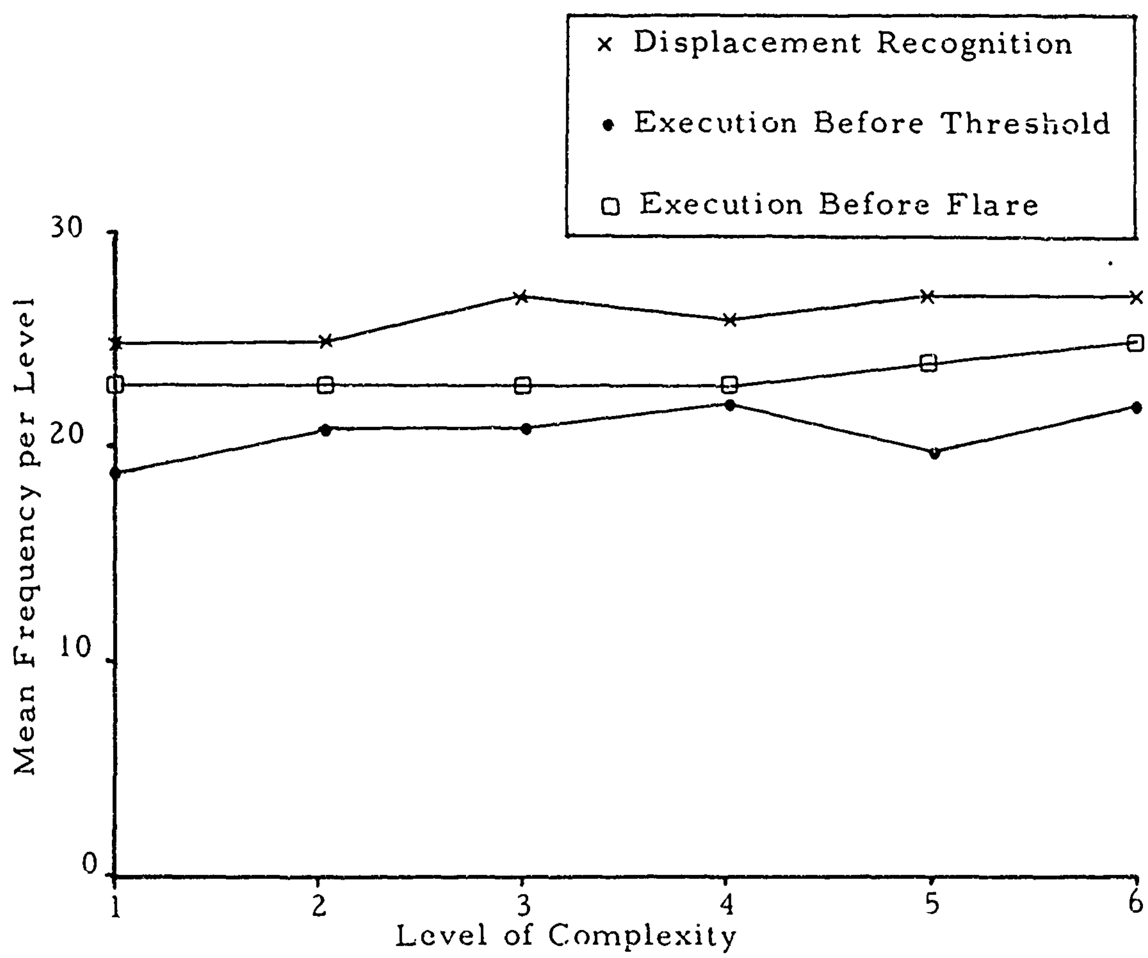

FIG. 5 COMPARISON OF RECOGNITION & EXECUTION SCORES.

In Table III we have tabulated the frequency with which undershoot "accidents" were observed under each combination of level of pattern complexity and axis of displacement. Because of the large number of "0" scores, no statistical analysis was undertaken with these observations, but it is interesting to note the strong tendency for these errors to accumulate at Level 4. Level 4, it may be recalled, is the point at which side rows were introduced. The possibility of this step producing confusion between the last 1,000 feet of approach lighting and the touchdown zone lighting was noted by participating pilots in their responses to the questionnaires and can be seen by inspection of Figure 1.

TABLE III

Frequency of Undershoots as a Function of Level of Complexity and Axis of Displacement

	Level of Complexity						
Frequency	1	2	3	4	5	6	Σ
A	2	0	1	1	0	0	4
D	1	3	1	3	3	1	12
H	0	2	3	6	0	0	11
Σ	3	5	5	10	3	1	27

Questionnaire Responses

In a variety of ways the outcome of this experiment confirms a feeling that the pilot can get along in most of his visually dependent tasks with very simple displays. The drive to complicate these configurations does not come from the results of live experiments. Live experiments often result in a loss of significance for characteristics or elements which were previously regarded as indispensable. An experiment on Category II runway marking has suggested such heresy with respect to the centerline in the touchdown zone (Reference 12). The pilots' subjective reactions in this study have a similar theme.

Level 1 participants found no gaps in the information flow from the single centerline and the same response was obtained from all other levels (Table IV, 1). As to new or unusual features, the elements missing in Levels 1-3 were noticed, as were the added elements in each step 3 through 6. (Level 3 does not really add elements since it is still only a partial reconstitution of Standard Configuration A). The lack of lateral or

TABLE IV

Summary of Post Test Questionnaire Responses

1. Flow of information.

Level	Continuous	Gaps	p	Comment
1	5	0	.031*	
2	4	1	.188*	Felt need for lateral guidance.
3	4	1	.188*	
4	4	1	.188*	
5	4	1	.188*	Felt need of information up to roll bar.
6	5	0	.188*	

2. New or unusual features?

Level	Yes	No	p	Comment
1	1	4	.188*	Lacks roll reference.
2	1	4	.188*	Lacks roll reference.
3	4	1	.376**	Termination bars, etc., missing.
4	4	1	.188*	Side rows.
5	5	0	.031*	Side rows.
6	4	1	.188*	Additional roll bar, but confused with runway lights.

3. Sufficient information from approach lights for corrections before threshold?

Level	Yes	No	p	Comment
1	3	2	.500*	
2	4	1	.188*	No lateral information.
3	3	2	.500*	
4	4	1	.188*	"It could be better."
5	4	1	.188*	
6	5	0	.031*	

*One-tailed binomial test.
**Two-tailed binomial test.

TABLE IV

Summary of Post Test Questionnaire Responses (Continued)

4. Quality of information on each axis of control.

	Heading				Roll				Attitude				Rate of Closure			
Level	E	G	F	P	E	G	F	P	E	G	F	P	E	G	F	P
1	3	1	1	0	0	2	1	2	0	1	3	1	0	3	1	1
2	1	4	0	0	0	1	1	3	0	1	3	1	0	1	3	1
3	0	4	1	0	0	1	2	2	0	0	1	4	0	1	4	0
4	4	1	0	0	3	0	1	1	2	0	1	2	1	2	1	1
5	3	1	1	0	1	1	2	1	1	2	1	1	1	2	1	1
6	2	3	0	0	0	3	2	0	0	4	1	0	0	3	2	0

E - Excellent G - Good F - Fair P - Poor

5. Does the configuration support Category II (1,200 feet RVR)?

Level	Yes	No	p	Comment
1	3	2*	.500*	Would be marginal.
2	2	3*	.500*	Need roll information.
3	2	3*	.500*	Need more light.
4	3	2	.500*	Lack of strong threshold.
5	3	2	.500**	Confuse center row approach with centerline of touchdown zone
6	4	1	.188**	

6. Was the 1,000-foot roll bar useful?

Level	Yes	No	p	Comment
1	NA			
2	NA			
3	5	0	.031*	Helped roll guidance.
4	3	2	.500*	Need better threshold.
5	3	2	.500*	Confused with threshold.
6	3	2	.500*	Confused with threshold.

*One-tailed binomial test.
**Two-tailed binomial test.

TABLE IV

Summary of Post Test Questionnaire Responses (Continued)

7. Would you like the same kind of information in landing zone?

Level	Yes	No	p	Comment
1	NA			
2	NA			
3	2	3	.500*	Would clutter.
4	2	3	.500*	
5	1	4	.188*	Would confuse.
6	4	1	.188*	Would like runway distance information.

8. Was transition from approach to landing zone distinctive?

Level	Yes	No	p	Comment
1	5	0	.031*	
2	4	1	.188*	Missed color.
3	5	0	.031*	Missed color.
4	2	3	.500*	Missed color.
5	1	4	.188*	Resemble touchdown lights.
6	5	0	.031*	

9. Did you have any trouble recognizing the threshold?

Level	Yes	No	p	Comment
1	0	5	.031*	
2	1	4	.188*	
3	0	5	.031*	
4	4	1	.188*	Confused approach and touchdown lights.
5	2	3	.500*	Confused 1,000-foot bar and threshold.
6	1	4	.376**	

*One-tailed binomial test.
**Two-tailed binomial test.

TABLE IV

Summary of Post Test Questionnaire Responses (Continued)

10. Notice any difference between test pattern and U. S. Standard Configuration "A"?

Level	Yes	No	p	Comment
1	5	0	.031*	Missed crossbar; flashers.
2	4	1	.188*	Miss crossbar; flashers and terminating and wing bars.
3	5	0	.031*	
4	5	0	.031*	Lacked termination and wing bars.
5	5	0	.031*	Missed crossbar, flashers, terminating and wing bars.
6	3	2	.500*	Missed strobes, roll bar, noted added side rows.

11. If you could redesign the configuration, what would you add?

Level	Roll Bar or Additional Cross Bar	Flashers	Color	Side Rows	VASI	Augment Threshold
1	3	2				
2	3		2			
3	1	2		1	1	
4		2		1		2
5	1	3	1			1
6	1	2	1			

12. What would you remove?

Level	Side Rows	Extra Crossbar
1		
2		
3		
4	1	
5	2	
6		1

*One-tailed binomial test.

TABLE IV

Summary of Post Test Questionnaire Responses (Continued)

13. How would you rate the quality of simulator?

	Flight				Visual			
Level	E	G	F	P	E	G	F	P
1	2	2	1	0	2	2	1	0
2	0	2	1	2	0	2	3	0
3	1	2	1	1	1	3	0	1
4	0	1	3	1	0	3	1	1
5	1	1	2	1	0	3	0	2
6	0	3	2	0	1	3	1	0
	4	11	10	5	4	16	6	4
	15		15		20		10	

roll orientation in Levels 1 and 2 was felt (Table IV, 2). Responses to Question 4 suggest that feelings of adequacy of roll, pitch, attitude, and to some extent rate of closure, improves at about Level 4. There was no decisive response suggesting belief that the configuration supports Category II, although performance results had indicated that with the exception of roll guidance the pilots could handle Category II with only the most elementary of configurations, the "center row."

Pilots who had the roll bar as an unambiguous element (Level 3) expressed the feeling that guidance was improved, but those flying the more elaborate systems (Levels 4-6) were less certain. There was a tendency to confuse the decision bar with threshold lights when side rows were also part of the configuration (Questions 6-9).

Several pilots missed elements of Configuration A that had been deleted to lay out the six-level building blocks concept—most obviously, of course, the 1,000-foot crossbar (Level 1, Question 10). Others did note the absence of wing bars and terminating bar, but these reactions were not immediate. They came after the subjects had had a little time to think about it.

In considering features they would like to add to their configuration, flashers were mentioned in all levels but Level 2. A roll bar loomed most important to this group, as to Level 1. Color was mentioned several times. (Color was not available in the simulator.) Side rows, on the other hand, were nominated for deletion by these subjects (Question 12).

Both flight and visual simulation were fairly well received (Table IV, Question 13), the visual component as usual getting a slightly more favorable reaction than the flight duplicator component.

Summary

Since the performance criteria applied in this experiment fail to discriminate among levels of pattern complexity, the selection of a basic configuration for further study must be based on considerations of operational practicality, pilot acceptance, and a logical analysis of guidance elements. From this point of view, it is believed that Level 3 represents a reasonable compromise of essential elements and desirable, if not entirely essential, characteristics that can be incorporated in the approach lighting at minimum cost. This pattern provides both heading and track alignment information quite adequately while offering a simple dominant cue for attitude and rate control (the large visual angle subtended by the threshold and the roll bar). Roll information is provided by the single

element previously responsible for this orientation* and without the elements that contribute to confusion with touchdown zone lighting. Finally, this configuration is the basic structure of the present National Standard Configuration A.

It was decided, therefore, that the basic center row and crossbar configuration provides a reasonable vehicle for further study of design requirements for Category II approach lighting. Experiment II was undertaken to show the feasibility of this minimum configuration for Category II operations, provided the pilots are given a reasonable opportunity to acquire and exercise the relevant skills. Experiment III in this series concludes the study with an analysis of the guidance functions of sequence flashing lights and an assessment of their value in relation to steady burning components of the system.

*Although roll displacements were not systematically introduced in Experiment I and were not included in the formal scoring protocol, the experimenter reported that it was quite obvious that roll guidance was seriously lacking at Levels 1 and 2 but came back strongly in Level 3.

EXPERIMENT II

One attraction in considering the basic center row and crossbar configuration (Level 3, Figure 1) as a point of departure in the evolution of an adequate, if not necessarily optimal, configuration for Category II operations is that it represents a minimum deviation from the present national standard. There are, in fact, certain elements that probably do not contribute significantly to the guidance value of the present system. One such element is the wing bar. The operational suitability test of narrow gauge touchdown zone lighting conducted at Dow AFB in 1959 (Reference 14) had, in fact, resulted in a recommendation that the wing bars be eliminated. Also, with the deletion of the termination bar and the extension of the center row of approach lights to the runway threshold, the threshold can function both as an indication of the beginning of the runway and the termination of the approach lighting configuration.* Thus the system is reduced to a center row extending 3,000 feet from the threshold with a roll, or decision, bar at 1,000 feet, all in white lights. (Figure 2). The experiment will concern itself with the ability of pilots to ilize this basic configuration in accomplishing satisfactory transition to visual flight under Category II (1,200 feet Runway Visual Range (RVR)) visibility conditions, given a reasonable opportunity to develop the required proficiency.

Experimental Method

The plan of the experiment (Table V) is based on the conventional learning experiment in which the subjects are exercised in the problem over a series of trials and their rate of progress in the direction of a satisfactory level of performance is noted. Six pilots chosen at random from NAFEC Flight Operations and six from qualified casual pilot sources flew a series of five training sessions consisting of eight approach and landing runs each day (a total of 40 runs for each pilot). The training procedure might be described as a combination of massed and distributed practice. The rationale for this approach was that the skill demand of Category II operations and the requirement to depend on a simplified approach lighting configuration constitute a combination of events that could depress pilot performance initially but might very well be overcome with a modest training effort. Any system that can become effective with such an effort might be regarded as an adequate system and should not be accepted or rejected on the basis of the pilots' initial reaction to it.

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*Present efforts to increase the brightness of the threshold lights should further improve their suitability for this function; continuous threshold lighting (in-pavement) is considered essential.

TABLE V

Experimental Design (Experiment II)

As a Function of Sessions

Subject Pilot	Session					Σ
1	1	2	3	4	5	
⋮	8 runs each					40
12						
Σ	96	96	96	96	96	480

As a Function of Axis of Displacement

Subject Pilot	H Heading	R Roll	D Track	A Attitude	Σ
1					
⋮	10 runs each				40
12					
Σ	120	120	120	120	480

Schedule for Each Subject Pilot

Session	Sequence								Σ
1	D	H	R	A	A	R	H	D	8
⋮									
5									
Σ (10 each axis)	5	5	5	5	5	5	5	5	40

In the end, a simplified system could be easier to learn and apply than the more complex systems in use and under consideration elsewhere.

The flight procedure utilized in this experiment is very similar to the procedure followed in Experiment I. Through controlled manipulation of the simulator flight environment, rotational displacements are introduced on each axis of flight in that part of the flight path in which the visual system is supposed to provide guidance information, and the pilots' ability to recognize these displacements and to control visually the rate at which they are corrected is analyzed. In this problem the displacements introduced were in roll, attitude, and heading with respect to the line of flight and track displacements left or right of the extended runway centerline.

Data were analyzed by appropriate application of the Friedman two-way analysis of variance technique and the binomial test (Reference 13). The scoring categories included:

1. (H) Heading correction (maneuver identification). Rotate or de-crab to the desired track or the same heading as the runway when cross wind is removed.

2. (R) Roll correction. Pilot must rotate to the same horizontal axis as the runway.

3. (A) Attitude (pitch correction) (maneuver identification). Rotate or correct attitude and rate of descent to maintain glide or flight path with projected impact at the ILS reference point.

4. (D) Displacement correction. Cross-track correction from a lateral displacement, resulting in alignment with centerline.

5. Rate of maneuver execution. Recorded as completed or not completed prior to crossing threshold.

Performance as a Function of Amount of Training

As was pointed out in the discussion in Experiment I, the pilot's performance on becoming visual and executing the maneuver indicated to him by the appearance of the visual scene could be analyzed in two parts, or phases. The first phase is the recognition of the direction of displacement indicated to the observer by the direction in which the pilot initiates his corrective control action. The second phase is the completion of this control action in time to place the airplane in a good attitude and position for landing, a continuing response that should be essentially completed

before the vehicle crosses the threshold. This phase requires the pilot to control the rate of correction or return to flight path by observing the rate of change in the visual scene as the maneuver is executed. The observer scores the success of the maneuver by noting whether the necessary correction has been completed prior to crossing the runway threshold.

Displacement recognition responses are shown in Table VI and Figure 6 with respect to amount of training. It can be seen that the pilots started out at a high level of proficiency in this task and showed no significant change in level of performance throughout the experiment. The slight drop in Session 5 is not significant. A two-way analysis of variance based on scores ranked across sessions produced no evidence of any significant gain or loss of proficiency as training progressed ($\chi r^2 = 2.75$, resulting in a probability between .5 and .7 for 4 df., see Table VI).

As in Experiment I, the pilots did find controlling the rate of execution of the corrective maneuver to be relatively more difficult than recognizing the direction of displacement (Table VI and Figure 6). In the course of training, this difficulty was progressively reduced, however, so that by the fifth session the maneuver was performed effectively 85% of the time (81 out of 96 opportunities for the group). The reason that the level of performance did not go higher may at least in part by attributed to the response inertia of the simulator which affects rate control efforts but not the control decision. A two-way analysis of variance based on scores ranked across sessions shows that the order of sessions with respect to performance is not random: There is a positive indication that learning is taking place ($\chi r^2 = 8.17$. For 4 d.f., probability is between .05 and .10, see Table VI). This impression is reinforced by a comparison of raw score means and variances as a function of sessions (Figure 7). While the mean level of performance is increasing, variability of performance is decreasing, a relationship usually indicative that a definite and positive learning process is taking place. It must be admitted that these means and variances are of doubtful validity as descriptors of the session by session performance score distributions because these distributions are obviously abnormal. The comparison is consistent, however, with the results of the distribution free two-way analysis of variance which has independently provided definite evidence that a true learning curve has been obtained.

The weight of the evidence seems to indicate that the novelty of the situation does present initial difficulty to pilots in accomplishing an effective visual transition, but that a reasonable opportunity for familiarization with the problem reduces this difficulty to practical dimensions.

TABLE VI

Summary of Performance Results

Criterion Measure	Mean Level of Performance Training Session 1	2	3	4	5	χ_r^2	df	p
Displacement Recognition	7.5*	7.7	7.5	7.4	5.7	2.75	4	.70 - .50
Rate of Execution of Corrective Maneuver	4.5*	5.4	6.2	6.7	6.8	8.17	4	.10 - .05

*Each pilot had 8 opportunities to perform at criterion level.

TABLE VII

Summary of Performance as a Function of Axis of Displacement

Criterion Measure	Mean Level of Performance Axis of Displacement Heading H	Roll R	Track D	Attitude** A	χ_r^2	df	p
Displacement Recognition	10*	10	8.8	7.9	23.65	3	< .001
Rate of Execution of Corrective Maneuver	6.3*	7.9	7.4	7.8	10.25	3	.02 - .01

*Total possible over 5 sessions = 10.

**The attitude recognition scores utilized in this analysis departed from the original scoring concept in that the judgment as to whether the pilot realized that he was experiencing an attitude displacement was made while the simulated wing ice condition was being applied, rather than after it had been removed. It is possible, therefore, that a few occasions were missed on which the pilot may have failed to recognize this condition while on instruments, but realized it after becoming visual. A thorough re-examination of the data, however, convinced the authors that no significant numerical discrepancy was introduced by this change in scoring procedure and that it was reasonable to proceed with the analysis as presented herein.

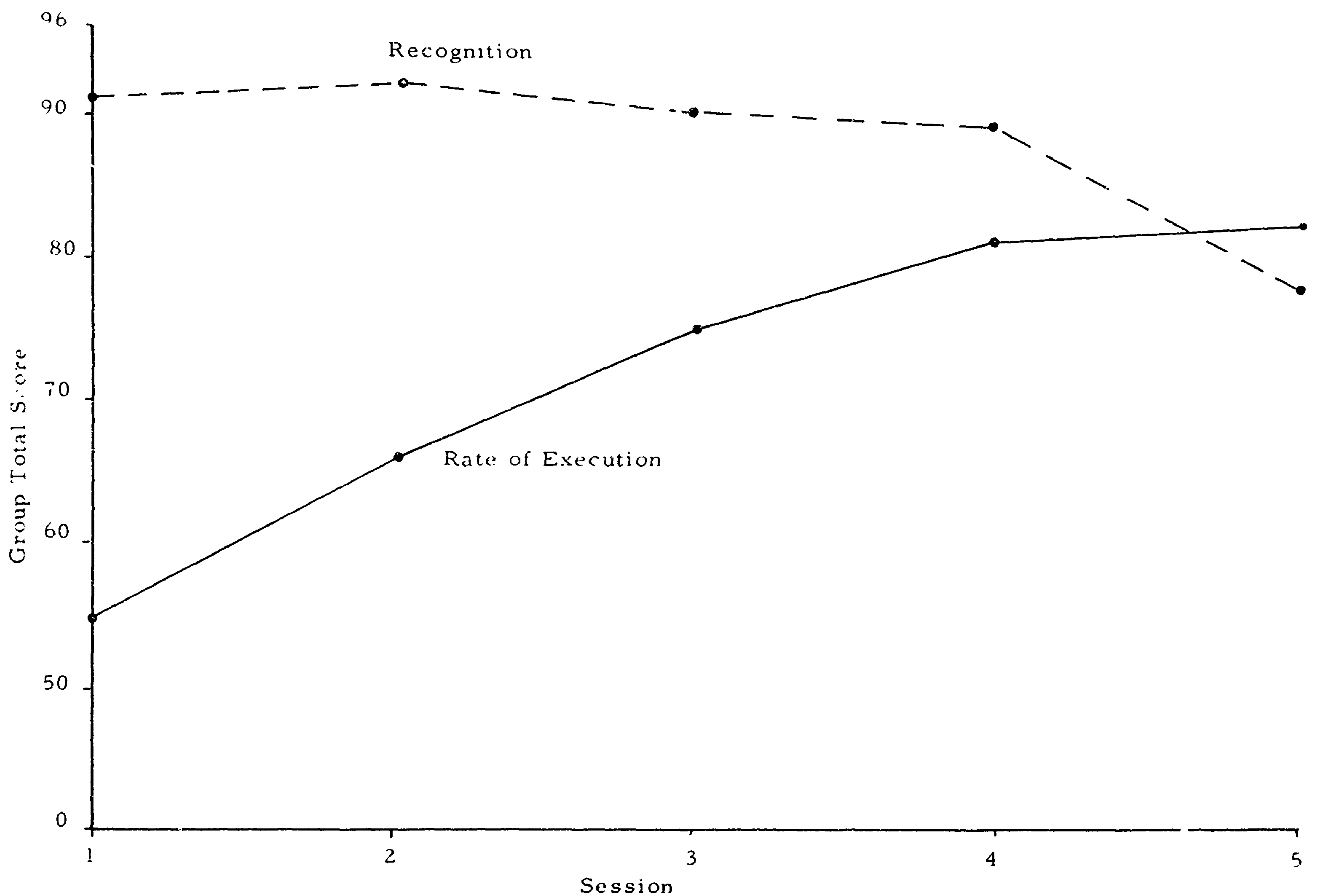

FIG. 6 GROUP PERFORMANCE TOTALS AS A FUNCTION OF TRAINING SESSION. TOTAL POSSIBLE FOR EACH SESSION IS 96(12S's X 8 RUNS EACH SESSION).

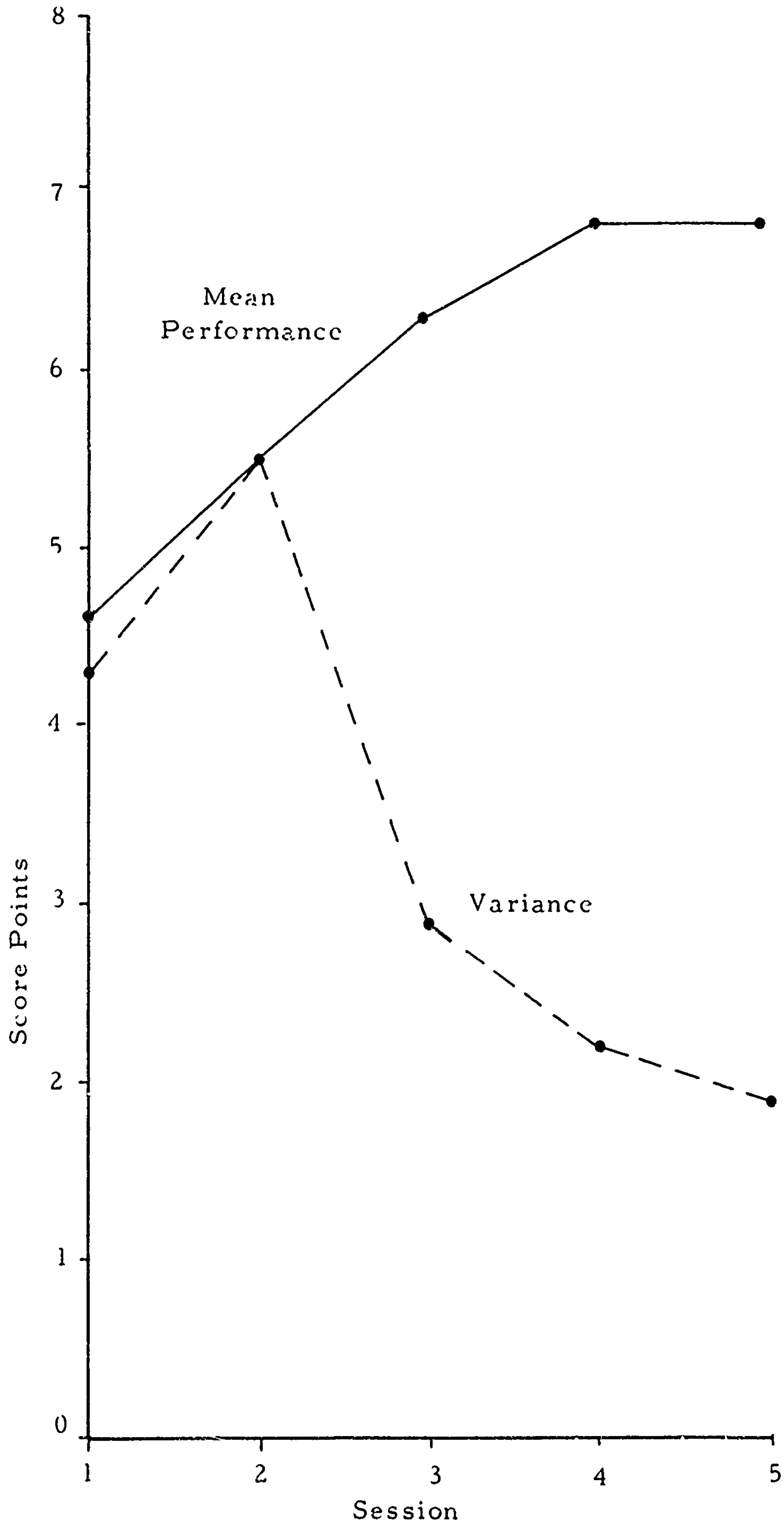

FIG. 7 MEAN LEVEL VS. VARIABILITY OF PERFORMANCE IN RATE OF EXECUTION OF THE CORRECTIVE MANEUVER.

Performance as a Function of Axis of Rotation and Track Displacement

A two-way analysis of variance of pilot performance in both displacement recognition and execution of the corrective maneuver indicates that both phases of pilot response vary with the axis of rotation (Table VII). In displacement identification the probability that the differences are random is less than .001. In rate of execution the probability is between .01 and .02. The order of effectiveness with respect to axis of rotation is different for rate scores in comparison with recognition scores (Figure 8). While heading displacements are the easiest to recognize, the compensatory response required is the most difficult to control, whereas attitude displacements are relatively difficult to recognize but relatively easy to control, once detected. A pilot may find it not too difficult to recognize his situation but relatively difficult to execute the indicated control action.

Overlaying the whole problem, of course, is the relative difficulty of carrying through a well paced control action with a flight simulator with the response latency characteristics of the P-3A as compared with the relative simplicity of indicating one's appraisal of the situation by the direction in which the control response is initiated. The authors suspect, nevertheless, that this is a rather general characteristic of the flight problem under the circumstances simulated.

Analysis of Pilot Judgments and Preferences

A summary of pilot post-test questionnaire responses is presented in Table VIII. Some rather interesting contrasts appear in the judgments offered, particularly with respect to the presence or absence of specific types of information and over-all judgments of the adequacy of the system. The pilots are unanimous in their opinion that the flow of information was continuous (Question 1)—a trait usually regarded as desirable and one, we believe, enhanced by the modifications made in the configuration for the test. Furthermore, there is a strongly positive judgment that sufficient information was obtained to make any necessary corrections prior to crossing the threshold (Question 3a); that except for roll, the quality of the information was good* (Question 3b); that there was sufficient time to make any corrections necessary before crossing the threshold (Question 4); that the transition from approach to landing zone lighting

*Actually, the pilots had little difficulty in recognizing or executing roll corrections. Their problems were more in the area of recognizing attitude displacements and correcting heading displacements.

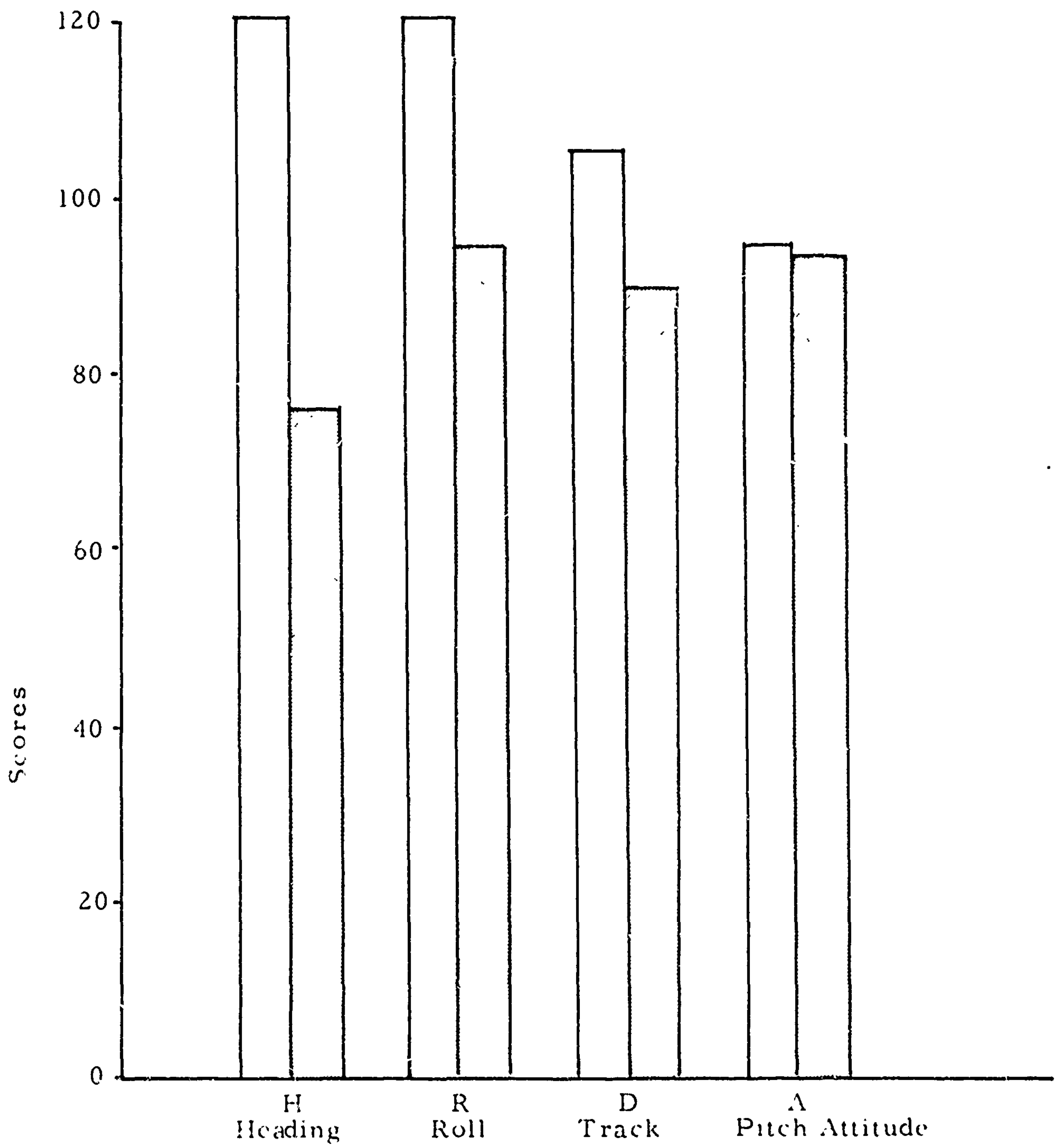

FIG. 8 SUMMATION OF DISPLACEMENT RECOGNITION ☐ & RATE OF EXECUTION ☐ SCORES AS A FUNCTION OF AXIS OF ROTATION. TOTAL POSSIBLE IS 120 (12 S's X 10 RUNS EACH AXIS).

TABLE VIII

Summary of Post Test Questionnaire Responses

Question	Response				p* (According to Binomial Test)
	Continuous	Gaps			
1. Was there a continuous flow of information from the approach lighting pattern or did you experience gaps?	12	0			.001
	Yes	No			
2. Do any features of the configuration strike you as new or unusual?	3	9			.073
3a. Did you obtain sufficient information from the approach lighting configuration to make any necessary corrections prior to crossing the threshold?	11	1			.003
3b. Quality of information obtained prior to crossing the threshold?	Heading	Roll	Attitude	Rate of Closure	
Excellent	3	1	0	0	
Good	6	3	8	7	
Fair	3	5	3	2	
Poor	0	3	1	3	
	Yes	No	No Answer		
4. Did you have sufficient time to make any necessary corrections before crossing the threshold?	10	1	1		.006

*One-tailed.

*One-tailed.

TABLE VIII

Summary of Post Test Questionnaire Responses (Continued)

		Response			
		Yes	No	No Opinion	p* (According to Binomial Test)
5.	In your opinion, will this configuration support Category II (1,200 feet RVR) operations?	4	7	1	.548**
6a.	The configuration has a warning or decision bar that tells you that you have 1,000 feet remaining before the runway threshold. Was this bar useful?	12	0		.001
6b.	Would you like the same sort of distance information in landing zone?	6	6		.613
7.	Deleted.				
8.	With the test configuration, is the transition from approach to landing zone lighting distinctive?	12	0		.001
9.	Did you have any trouble recognizing the runway threshold?	1	11		.003
				Not Answered	
10.	Do you recognize any differences or changes between the pattern you flew and the U. S. Standard Configuration A?	9	1	2	.011
11.	Deleted.				

*One-tailed.
**Two-tailed.

TABLE VIII

Summary of Post Test Questionnaire Responses (Continued)

12. How would you rate the quality of simulation in this experiment?	Response: Flight (P-3)	Visual
Excellent	4	2
Good	7	8
Fair	1	2
Poor	0	0

was distinctive (Question 8); and that they had no trouble recognizing the runway threshold (Question 9). Yet 7 out of the 12 pilots felt that this configuration would not support Category II operations!

To the question "Do any features of the configuration strike you as new or unusual?" 9 out of 12 say "no" (Question 2). At the same time, 9 out of 12 say that they recognized differences between this configuration and the Standard Configuration A (Question 10). (It should be noted, of course, that the major elements of the configuration were not changed.) Finally, the pilots are unanimous in their judgment that the 1,000-foot warning or decision bar was useful (Question 6a), yet only half are willing to say that they would like the same kind of information in the landing zone (Question 6b).

These responses serve to emphasize one of the cautions that ought to be observed in the use of questionnaires. Questions relating to the presence or absence of specific events can be answered with minimum susceptibility to the common errors of opinion or attitude responses and can be checked for internal consistency with related questions and with empirical observations. Questions 3a, 4, 8, and 9 tend to fall into this category. The responses to those questions are internally consistent and generally consistent with actual performance. Questions on generalized qualities, however, are maximally susceptible to personal bias, and it is difficult to judge what the respondent is actually thinking about when he gives his answer. Responses to such questions are difficult to interpret and often completely inconsistent with performance. Question 5 is an example of such a question. (Another question of this sort is "Which system has the most guidance value?") What one pilot is thinking about when he makes such a gross judgment might be entirely different from what another pilot is thinking about. In this case, it happens also that the answers given were on the whole totally inconsistent with their objective experience or with the responses regarding specific guidance characteristics. (They could and did use the system under Category II conditions.) Most of the rest of the questions tended in this direction and, not surprisingly, are marked by the ambiguity of response that has been noted. Over-all, the questionnaire method should be regarded as a strictly secondary source of information when performance data are available.

The main value of the questionnaire would appear to be in determining the subject's understanding of the points at issue; his readiness to accept new equipment or procedures; or the kind of response made when he is presented with a forced choice immediately after having performed tasks dependent on the system or procedures between which the choice is to be made. Much depends, as has been pointed out, on the manner in

which the questions are asked—specific questions regarding the presence or absence of system characteristics involved directly in the stimulus-response situation tend to be interpreted in the same way by most respondents. Generalized questions regarding the operational employment or value of a system often mean entirely different things to different people.

Summary

In this experiment the ability of a simplified version of the U. S. Standard Configuration A Approach Lighting System to support Category II operations was examined. Twelve pilots were provided with an opportunity to practice instrument to visual approaches with this system over a period of 5 daily 8-trial sessions—a total of 40 trials each. Rotational and track displacements were systematically imposed, and the pilots' performance evaluated with respect to their ability to recognize these displacements visually and to pace effectively the appropriate control response. The results showed that the configuration adequately indicated the direction of displacement from the very beginning and that no learning or improvement in skill was required to utilize it effectively for this purpose. Effectively pacing the control response, i.e., tracking the rate of change in the visual scene as the control response was underway so that the result was a good aircraft position and attitude for the final landing maneuver, did require some learning. Before the end of the series of training sessions performance had reached a level of efficiency reasonably approaching the limit that might be expected as a function of the flying qualities of the P-3A flight simulator.

Performance was also analyzed with respect to the axis of rotation. This analysis showed that the order of difficulty in displacement recognition was different from the order of difficulty in execution. Heading displacements were easily recognized but difficult to control, attitude displacements were relatively difficult to recognize but not so difficult to control, once recognized. The order of effectiveness in performance in each case appeared as follows:

Displacement Recognition	$H = R > D > A$
Rate of Correction	$A = R > D > H$

In general, execution of the corrective maneuver was a much more difficult task than recognition of the direction of response required. Given time for the development of the appropriate skills, however, both tasks were effectively supported in Category II visibilities by the simplified Configuration A.

EXPERIMENT III

Sequence flashing, or strobe, lights are included as an optional feature of the U. S. National Standard Approach Lighting System because it is assumed that under reduced visibility conditions the flashing feature of these lights would help the pilot to locate the instrument runway and achieve initial alignment with the extended centerline*. Transition to full visual guidance as provided by the steady burning light components would then take place under conditions where the pilot's initial alignment permitted him to take full advantage of the total system.

Experiment III in this series concerns itself with this and other questions bearing on the visual guidance value of the sequence flashing lights. Three configurations are considered: basic center row and crossbar pattern in steady burning lights (B); basic center row and crossbar configuration with sequence flashing lights added (S+B); and sequence flashing lights alone (S). The main operational question is whether any significant contribution to the information content of the display should be expected from the addition of strobe lights to the system.

There are reasons to suspect that not all of the effects on pilot performance will be positive. While the strobes should decrease approach light detection latency (i.e., the pilots will see them earlier), and the illusion of the ball of light moving along the centerline toward the runway should aid the pilot in achieving lateral alignment, in other respects the effect could be negative. The distracting quality of the moving light could make recognition of axis of displacement more difficult, and could also interfere with visual tracking performance to a sufficient degree to slow down execution of the corrective maneuver. Finally, there is a tendency for pilots to avoid closing on the bright flashing lights with the result that flare out will tend to be premature — i.e., they will level off high. All of these possibilities are investigated in this experiment.

Since the factorial design of the experiment permits independent assessment of the effects of axis of displacement, a number of points of

*In order to control the flash rate and to pack a lot of light in a very short interval, the sequence flashing light system usually employs condenser discharge lights. Rather magical qualities have been claimed for these lights—their ability to penetrate fog, to reach high supra-threshold brightness levels without destroying dark adaptation, etc. None of these questions is being assessed in this study, however, because only the dynamic or flashing character of the lights is being simulated. Comment on the visual effects of condenser discharge lights as a source may be found in Reference 1 for those who are interested.

interest in pilot performance and task difficulty will also be explored. This feature of the design also permits a check on our success in achieving control of axis of displacement in the experimental manipulation of the flight environment.

Experimental Method

The plan of the experiment (Table IX) is based on a three by three factorial design in which there are repeated measures on both factors. McNemar refers to it as a three-way classification in which the rows stand for persons or matched individuals (Reference 5). In the application of this design the interaction between the variables of interest and subjects is used to test the main effects. Simple interactions are tested by the three-way interaction. Since the interactions must be used to test the independent variables, there is no independent estimate of error and there is some loss of generalizability with the design. The sensitivity of the experiment is increased over that to be expected by random assignment of subjects to variables, however, in that each subject serves as his own control. Individual differences are not a factor and are of no interest in the analysis.

The plan of the analysis is shown in the analysis of variance summary tables in Appendix D. An arcsin scale transformation was applied to scores that could be expressed as proportions in order to normalize the distributions.

Four of the five subjects were selected from the NAFEC casual pilot population, all with military ratings in multi-engine aircraft. One subject was drawn from the operational pilot group. All were given sufficient flight familiarization in the simulator to achieve a satisfactory degree of proficiency as judged by the experimenter, who was a qualified pilot and simulator instructor, with the concurrence of the subject-pilot himself. Each subject flew a series of 6 sessions consisting of 9 approaches per session, for a total of 54 runs per pilot and 270 for the experiment.

In a pre-test briefing each subject was advised that he was participating in an experiment directed toward the determination of the guidance value of sequence flashing lights. The balance of the subject briefing and flight procedure was the same as that of Experiments I and II, except that in this experiment the subject actuated an event marker button mounted on the control wheel to indicate the point of first contact with the approach lights. The experimenter also used an event marker for the same purpose. Remembering that the experimenter has a full view of the simulator projection screen and knows exactly when to look for it, his observation might be regarded as a record of approach light detection under optimal conditions

TABLE IX

Experimental Design (Experiment III)

Configurations

S - Sequence flashing lights only.
B - Steady burning lights only (in basic center row and crossbar pattern).
S+B - Sequence flashing lights on steady-burning center row and crossbar pattern.

Axis of Displacement

Attitude	- Aircraft is displaced on pitch axis at time of visual transition to approach lighting.
Displacement in Track	- Aircraft is displaced left or right of extended runway centerline at time of visual transition.
Roll	- Aircraft is rotated on roll axis at time of visual transition.

Number of Trials

Axis of Displacement	S	B	S+B	Σ
A	6	6	6	18
D	6	6	6	18
R	6	6	6	18
Σ	18	18	18	54

Schedule

Session	No. Trials	Sequence		
1	9	$S+B_{ADR}$	B_{RDA}	S_{ADR}
2	9	S_{RAD}	$S+B_{DAR}$	B_{RAD}
3	9	$S+B_{DRA}$	B_{ARD}	S_{DRA}
4	9	S_{ADR}	B_{RDA}	$S+B_{ADR}$
5	9	$S+B_{RAD}$	B_{DAR}	S_{RAD}
6	9	S_{DRA}	$S+B_{ARD}$	B_{DRA}

(predetermined fixation point and no requirement for visual search), or an "intrinsic detection response." The subject's observation, on the other hand, is made under search conditions with the added distraction of flying an ILS approach up to the point of visual transition. His report might be regarded as an approach light "search detection response." Approach light detection latency as used in this study is the interval separating the search detection response from the intrinsic detection response.

Another departure in observational procedures from the preceding experiments was the experimenter's recording of the point of completion of the corrective maneuver independent of landmarks such as the roll bar or runway threshold. When he judged the displacement to have been recovered, the experimenter activated an event marker which placed a mark on the time line of the Brush recorder. The score used in the analysis was the interval between this marker and the ILS reference point, 1,000 feet from the runway threshold.

The six channel Brush Pen Recorder, Model RD 2361, on which the events described above were recorded, was also used to record longitudinal and lateral positioning at touchdown. Details of the recorder set up are included in Appendix A.

The complete list of scoring categories included:

1. Detection latency. Temporal interval between subject pilots "search detection response" and experimenter's "intrinsic detection response."

2. Displacement recognition. At the time of transition to visual flight the pilot initiates:

a. Roll correction (R) toward the same horizontal axis as the runway.

b. Displacement correction (D), an appropriate turn toward alignment with the extended runway centerline.

c. Attitude correction (A), a pitch rotation toward the glide or flight path with projected impact at the ILS reference point.

3. Rate of maneuver execution. Point at which the displacement correction has been completed with respect to certain criteria (before roll bar, bef re threshold, before flare) and position at time of maneuver completion with respect to the ILS reference point.

4. Flare path, or rate of closure. Whether pilot leveled off high, leveled off low (i.e., flew into the ground) or closed in a normal flare asymptotically with the runway.

5. Lateral positioning at touchdown. Placement of aircraft left or right of centerline within touchdown zone lighting, and absolute distance laterally from runway centerline at touchdown.

6. Longitudinal positioning at touchdown. Placement of aircraft at touchdown within first 1,000 foot segment, second 1,000 feet, or third 1,000, and absolute distance from threshold at touchdown.

Performance Results

Pilot performance has been analyzed in two major categories: configurational effects and displacement effects. A summary of analysis of variance results in both categories appears in Table X for sources of variation on which the hypothesis that the results are random can be rejected at the 1%, 5% or 10% levels of confidence. The first column identifies the criterion measure, the second column the source of variation (configuration, axis of displacement or an interaction between configuration, axis of displacement, or the subjects involved), the third column the variance (F) ratio, the fourth column the degrees of freedom used in evaluating the statistical significance of this variance ratio, and the last column on the right indicates the probability that the variance ratio might have been obtained by chance, i.e., that the effect is random. Effects rated at the 1% or 5% levels of significance can be accepted with a high degree of confidence that they cannot be explained as products of experimental error. Effects rated at the 10% level tend in the same direction but must be accepted with caution.

Tables XI and XII, and Figures 9 and 10, present an interpretation of these effects in operational terms and real numbers. Since the primary interest is in the configurational effects—i.e., the guidance value of strobes—these will be taken up first.

It will be recalled that a number of operational effects were predicted for the employment of sequence flashing lights. These predictions are reiterated in Table XI and compared with the experimental outcome. For convenience in interpreting this outcome, the letters opposite each prediction in Table XI correspond to the letters identifying graphs in Figure 9.

The most important effect anticipated for sequence flashing lights was an increase in detection range (Table XIa and Figure 9a). This expectation was confirmed. The attention getting value of the moving light

TABLE X

Summary of Analysis of Variance Results in Which Ho is Rejected at the 1%, 5%, or 10% Level

Criterion Measure*	Source of Variation	F	df	p
a. Detection Latency	Configuration (C)	13.562	2/8	.01
	Configuration x Subjects Interaction (CxS)	2.570	8/16	.10
b. Displacement Recognition	Axis of Displacement (A)	22.125	2/8	.01
	Configuration (C)	5.673	2/8	.05
	AxC Interaction	2.788	4/16	.10
c. Rate of Execution				
1. Approach time remaining to ILS intercept	Axis of Displacement	3.665	2/8	.10
	Configuration	4.914	2/8	.05
2. Completed before roll bar	Configuration	19.845	2/8	.01
	AxS Interaction	4.508	8/16	.01
3. Completed before threshold	Axis of Displacement	6.469	2/8	.05
d. Rate of Closure (Flare Path)				
1. Leveled off high	Axis of Displacement	7.440	2/8	.05
	Configuration	3.557	2/8	.10
	AxC Interaction	4.780	4/16	.01
2. Leveled off low	Axis of Displacement	5.386	2/8	.05
e. Lateral Positioning at Touchdown				
1. Touchdown within touchdown zone lights	Axis of Displacement	3.500	2/8	.10
2. Average deviation from centerline	Axis of Displacement	3.327	2/8	.10
	Configuration	2.988	2/8	.10
	AxC Interaction	4.231	2/8	.05

*Raw score summary tables corresponding to the same criterion measures appearing in Appendix E.

TABLE X

Summary of Analysis of Variance Results in Which Ho is Rejected at the 1%, 5%, or 10% Level (Continued)

Criterion Measure*	Source of Variation	F	df	p
f. Longitudinal Positioning at touchdown				
1. Distance from threshold	Axis of Displacement	6.424	2/8	.05
	AxS Interaction	9.021	8/16	.01
	CxS Interaction	2.668	8/16	.10

*Raw score summary tables corresponding to the same criterion measures appearing in Appendix E.

TABLE XI

Expected vs. Obtained Configurational Effects

Criterion Measure	Expected	Obtained
a. Approach Light Detection Latency	Strobes will decrease latency.	Confirmed.
b. Displacement Recognition	Strobes will degrade performance.	Not confirmed. Performance best with sequence flashing and steady burning light (S+B) combination.
c. Rate of Execution: Approach Time Remaining at Maneuver Completion	Strobes will degrade performance.	Not confirmed. Performance best with S+B combination, although worst with strobes alone.
d. Rate of Execution: Frequency of Maneuvers Completed Before Roll Bar	Strobes will degrade performance.	Confirmed. Performance best with steady burning lights.
e. Flare Path	Strobes will induce tendency to level off high.	Confirmed.
f. Lateral Positioning Error	Strobes will aid alignment, reduce error.	Not confirmed. Performance is best with steady burning lights.

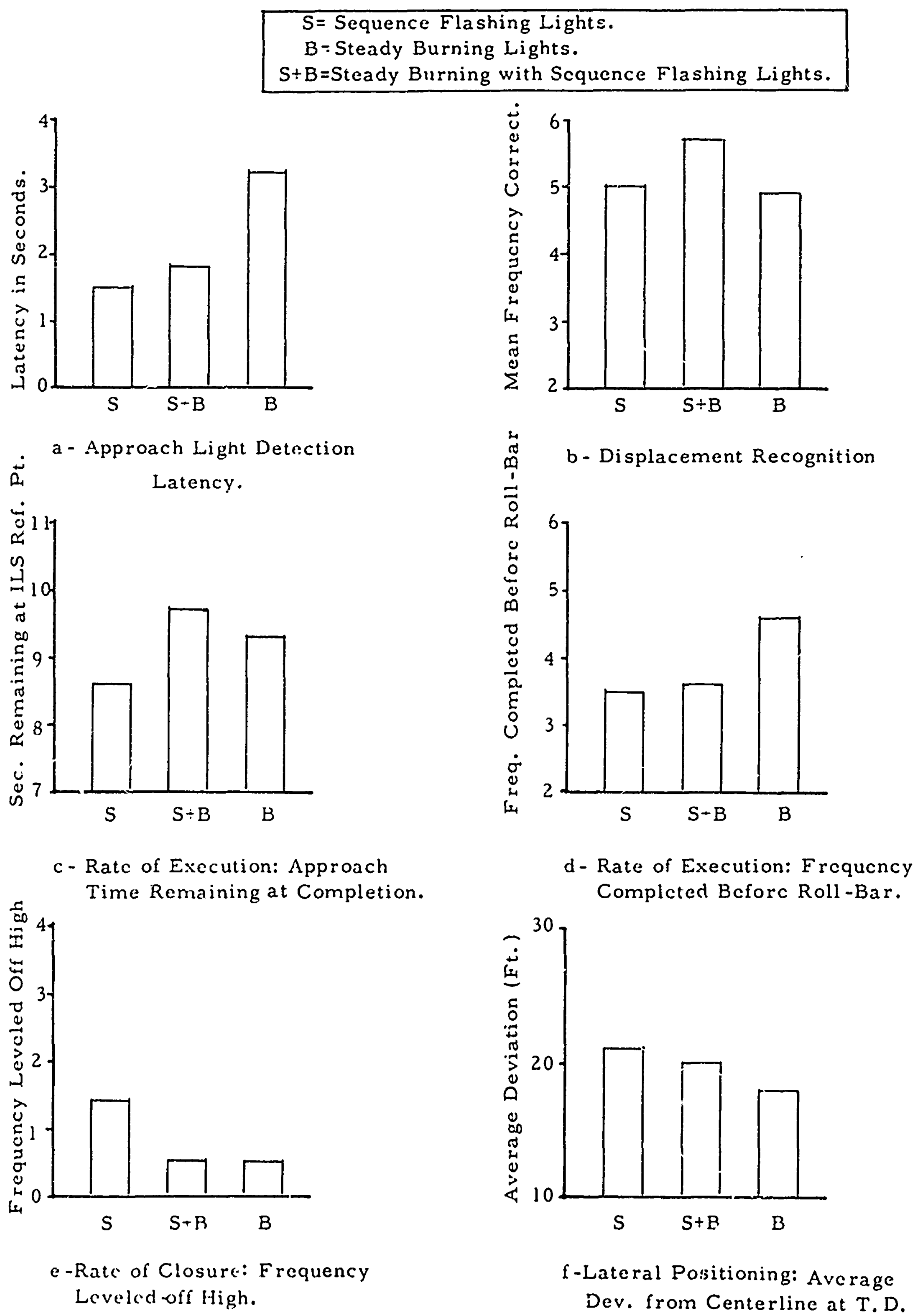

FIG. 9 CONFIGURATION EFFECTS.

did work to increase the probability of early detection. At the same time it was forecast that the addition of the strobes would break up the configurational quality of the steady burning array sufficiently to make displacement recognition more difficult (Table XIb and Figure 9b). This prediction was not confirmed. Performance was best with the strobe light/steady burning light combination. Following on the prediction regarding displacement recognition, it was anticipated that the presence of the strobe lights would have a sufficient distracting quality to slow down the rate of execution of the corrective maneuver—i.e., the performance of the compensatory tracking task. This prediction was partially confirmed. In terms of time remaining before ILS reference point after completion of the corrective maneuver (Table XIc and Figure 9c), it would appear that the earliest completions, on the average, occurred with the strobe light/steady burning light combination. The least effective performance in this respect, however, was exhibited when the pilots had to depend on strobes alone. And when the criterion measure is frequency of completions prior to crossing the decision bar—an operationally important landmark—the best performance is with the steady burning lights (Table XId and Figure 9d). Both strobes alone and strobes plus steady burning lights are less effective. It appears possible that the common factor holding up performance on both of these measures of rate of execution is the steady burning light pattern, whereas, over all, the strobes tend to depress it. Continuing on the approach path, it was predicted that pilots would tend to hold back closing on the strobes and consequently would ride a little high in glide path as they initiate their rotation for flare-out, ending up by leveling off high. This prediction was confirmed (Table XIe and Figure 9e). Finally, it was expected that the apparent movement of the light along the extended centerline of the runway would improve the pilot's ability to achieve lateral alignment. This prediction was not confirmed—steady burning lights were most effective in reducing lateral error at touchdown (Table XIf and Figure 9f). (Since the axis of displacement by configuration interaction is significant, a possible explanation for this tendency toward larger lateral displacements with strobe lights is suggested by the relationship between attitude displacements and strobe lights discussed in the following paragraph.)

Interaction effects involving configurations appear in measures of approach light detection latency, displacement recognition, flare path, lateral positioning at touchdown, and longitudinal positioning at touchdown. These effects are not of primary interest and are sometimes difficult to interpret, but some idea of their nature can be had by examining the appropriate raw score summaries in Appendix E. The configuration by subjects (CxS) interaction in approach light detection latency, for example, means that some subjects were strongly affected by the presence of strobe lights, some were not. Subject #5 was very little affected; Subject #4,

very strongly. His performance benefited significantly from the addition of sequence flashing lights. In displacement recognition, the configuration by displacements interaction (AxC) suggests that on roll displacements performance is very little affected by the configuration—a surprising discovery when it is recalled that the sequence-flashing-only alternative has no pattern elements intended to provide horizontal orientation. It is possible, of course, that in the absence of information in the lighting system, the pilots resorted to flight instruments or to uncontrolled extra-cockpit cues. The primary effect of configuration is on attitude displacements. In this case, the combination of steady burning and strobe lights appears to be most effective. In achievement of an optimal flare path (rate of closure), the axis of displacement by configuration interaction (AxC) table in Appendix E shows that the effect of strobe lights is almost exclusively on attitude displacement. The direction of displacement and the presence of the strobe lights without a steady burning light background work in the same direction to drive the pilot high on glide path into the flare maneuver. Track and heading displacements show little effect of these configurational changes insofar as flare path is concerned. In lateral deviation from centerline, the axis of displacement by configuration interaction (AxC) shows the major effect of strobe lights alone to occur in connection with attitude displacements, while the combination of steady burning and strobe lights produces its major effect during track displacements, as expected. Apparently the pilot's concentration on attitude under conditions where he has been subjected to a combination of strobe lights and deliberate displacement in attitude causes him to pay less attention to lateral control.

In the configuration by subjects interaction (CxS) in longitudinal positioning at touchdown, Subjects 1, 4, and 5 tend to make their longer landings after having approached over the strobe/steady burning light combination. Subjects 2 and 3 make their shortest. The effect of sequence flashing lights on longitudinal positioning at touchdown depends on the pilot—some are affected one way, some another.

Over-all, however, it can be said that the sequence flashing lights accomplished their purpose of increasing detection range without any important adverse effects on the guidance value of the system. In this respect, the results of this experiment are in general agreement with previous work in both laboratory (References 2 and 3) and operational test (Reference 4) situations.* The tendency to extend the glide path

*The finding that sequence flashing lights increase approach light detection range has been confirmed and extended to simulated Category II day fog

and the failure to improve lateral alignment, however, suggest that the optimal operating procedure would turn off the strobes as soon as the pilot has acquired the steady burning lights and recognized his displacement—i.e., made his commitment to land. Probably the best way to do this is simply to terminate the strobe light installation at the decision bar. In this way the pilot next in the landing sequence would still have the sequence flashing lights available while the preceding pilot is completing his approach.

For the most part axis of displacement effects were confirmed, including some that help to confirm a belief that the experimental manipulation of flight environmental conditions was successful. Following the results obtained in Experiment II (see Figure 8), it was anticipated that attitude displacements would be most difficult to recognize, roll displacements the easiest. This expectation was confirmed (Table XIIa and Figure 10a). Furthermore, since roll displacements require a simple rotation on the longitudinal axis to correct, it was believed that execution of the corrective roll maneuver would reach criterion levels most often. This prediction was confirmed with respect to completions before crossing the threshold (Table XIIc and Figure 10c), but not with respect to time remaining between completion and the ILS reference point (Table XIIb and Figure 10b). Track displacements were recovered with the most time remaining. The most probable explanation for this is the timing of the experimental displacements. Roll displacements took effect after the pilot made his visual transition. Track displacements, however, were present as the visual transition took place. When initiated, therefore, track displacements would be completed earlier than roll displacements, although they were not as often correctly executed within the criterion zone. Interaction effects involving axis of displacement showed that some pilots have difficulty controlling the correction of track displacements (see next paragraph).

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conditions in a recently completed experiment on runway marking patterns. In the marking experiment half of the 10 subjects flew with strobe lights, half without strobe lights, in the approach lighting system. Based on observational and scoring procedures modeled closely after those reported here, the approach light detection latency for pilots flying without strobes was 5.6 seconds. Latency for pilots flying with strobes was 4.0 seconds, a difference of 1.6 seconds which is significant between the .05 and .02 levels of confidence ($t = 2.35$, for 8 d.f., $p = .05 - .02$). Equipment used was the same as that reported in the present study with the exception that a low visibility, high brightness daylight contact fog environment was being simulated. A report on the experiment is under preparation.

TABLE XII

Expected vs. Obtained Displacement Effects

Criterion Measure	Expected	Obtained
a. Displacement Recognition	Will be best with roll; poorest with attitude displacements.	Confirmed.
b. Rate of Execution: Time from Completion to ILS Reference Point	Roll corrections will leave most time .	Not confirmed. Track displacements left the most time.*
c. Rate of Execution: Completion Before Threshold	Roll displacements will be least affected; easiest to recover.	Confirmed.
d. Flare Path High	Attitude displacements force high on approach.	Confirmed.
e. Flare Path Low	Converse of above; attitude displacements will show least effect.	Confirmed.
f. Touchdown Distance From Threshold	Attitude displacements will extend the glide.	Confirmed.
g/h. Lateral Positioning Error	Will be maximum with track displacements.	Confirmed.

*Possibly an artifact of procedure (see discussion on p. 44)

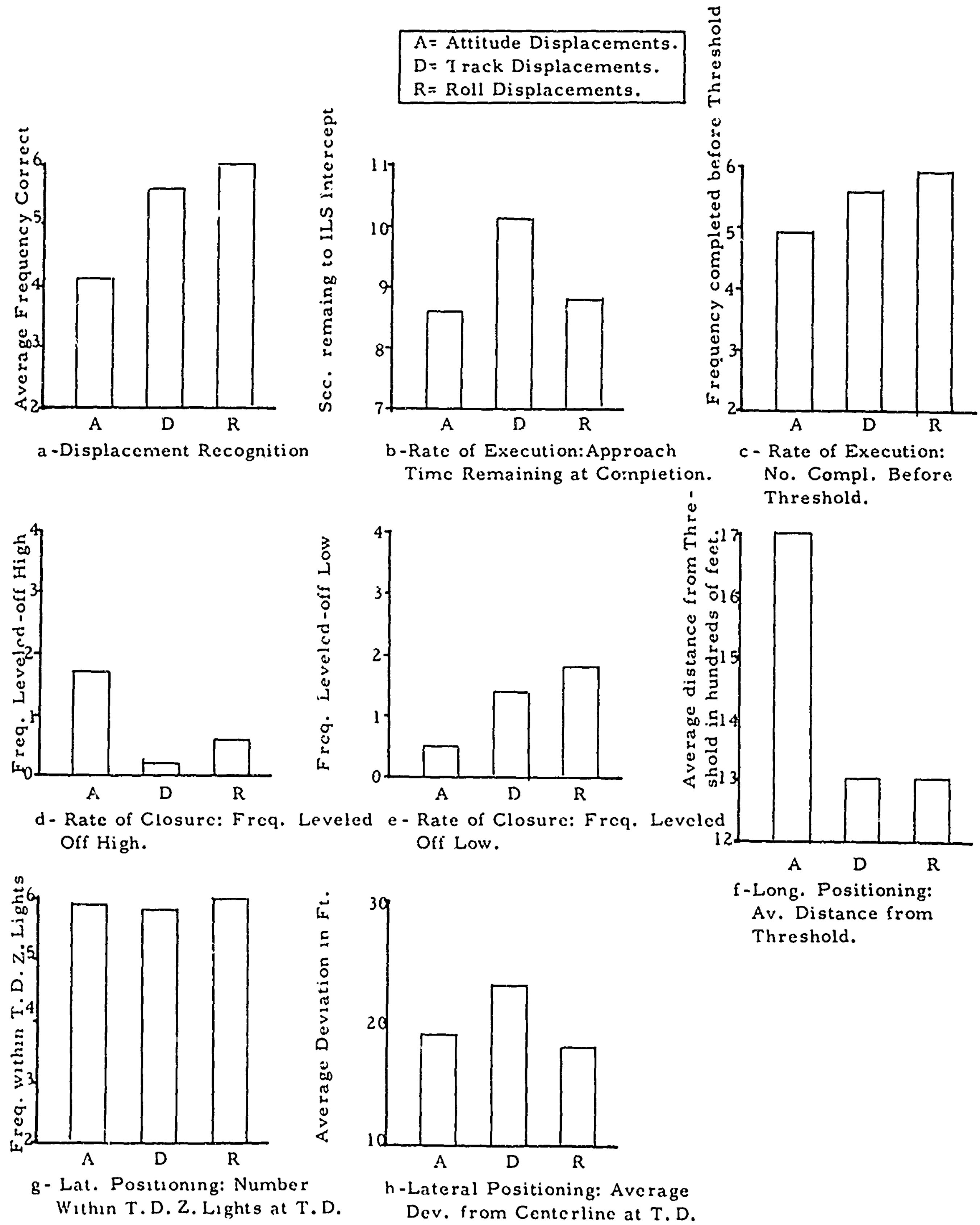

FIG. 10 DISPLACEMENT EFFECTS.

Because attitude displacements deliberately place the subject high on glide path, it is not surprising that the occasions on which the pilot levels off high after such displacements are more frequent, or that the frequency with which he levels off low is less (Table XIId and e, and Figure 10d and e). These effects confirm our success in experimentally inducing displacements on the pitch axis. The finding that attitude (or vertical) displacements extend the glide (Table XIIf and Figure 10f) further confirms the success of experimental control as does the finding that lateral positioning error is maximum with track displacements (Table XIIg and Figure 10f and g).

Some of the interaction effects involving axis of displacement have been discussed in connection with the configurational effects with which they were associated. Brief mention might be made here of certain interdependencies limited to interactions between pilots and displacement conditions (AxS interactions). One of these appears in rate of execution in the frequency with which the corrective maneuver is completed before crossing the roll bar. Examination of the AxS interaction raw score table in Appendix E suggests that although all pilots have more difficulty with attitude displacements than track or roll displacements, pilots 1, 3, and 4 also have difficulty with track displacements. Pilots 2 and 5, on the other hand, show their best performance with track displacements. In longitudinal positioning at touchdown, there is a general tendency to make longer landings after attitude displacements, as pointed out above, but pilots 4 and 5 are much less affected by this condition than pilots 1, 2, and 3 (AxS interaction table). They tend to land longer regardless of the axis of displacement.

<u>Questionnaire Responses</u>

In their pre-test questionnaire responses, the pilots all expressed the view that the sequence flashing lights were an essential component of low visibility approach lighting systems, basing their judgment primarily on beliefs that they are easier to detect and aid in alignment ("lining up") (Table XIII). The first of these assumptions was supported by the experimental results, but some doubt was placed on the second.

In post-test questionnaire responses the pilots reiterated their belief in the attention getting value of the strobe lights (Questions 1, 2, 3 and 8, Table XIV). They still expressed confidence that the strobes would improve the heading (alignment) guidance offered by the approach lighting system, although this judgment was not supported in their performance (Questions 4 and 5). They did not feel that other guidance

TABLE XIII

Summary of Pre-Test Questionnaire Responses

Question	Subject	Response
1. Do you believe sequenced flashing lights to be an essential component of low visibility approach lighting systems?		Yes 5 No 0
2. Why do you feel this way? What, in your opinion, is the main reason these lights should (should not) be part of system?	1	They give a distinct reference, they assist in lining up, and helpful for marking the runway when you are not exactly lined up on breakout.
	2	Greatly increased directional information is provided the pilot prior to reaching the TH area. Flashers are much easier to pick up and give a better "feel" of direction to the pilot approaching the runway.
	3	Sequenced flashing lights provide a better visual means of transition than steady lights.
	4	In low visibility situations, they should provide azimuthal information, to get the runway centerline, that should be better than other means of penetrating visibility restrictions.
	5	Believe they are required for acquisition of the system prior to 200 feet under certain light/fog conditions. They can be cause of missed approaches/landings due to brightness settings. It is my belief that air crew should have control of brightness and on/off by means of radio frequency keying.

TABLE XIV

Summary of Post Test Questionnaire Responses

Question	Response			p
1. Are sequence flashing lights an essential component of low visibility lighting systems?	Yes	4	Combined with fixed lights.	.188*
	No	1	Good only if can turn on-off from cockpit	
2. Able to recognize approach lights earlier with strobes?	Yes	5	-	.031*
	No	0	-	
3. Did flashing lights make recognition of fixed approach lights?	More difficult? 1	Less difficult? 4	No difference? 0	

4. What was the quality of guidance obtained from strobe lights alone?

Guidance Category	Good	Fair	Poor	Negligible	No Response
System recognition	3	0	0	0	2
Heading guidance	4	1	0	0	0
Roll guidance	0	0	3	1	1
Attitude guidance	0	0	3	1	1
Rate of closure	1	2	1	1	0

5. Do strobe lights add or subtract from guidance obtained from steady burning lights?

Guidance Category	Adds	Subtracts	No Response
Heading	5	0	0
Roll	1	1	3
Attitude	1	1	3
Rate of closure	2	1	2

*One-tailed binomial.

TABLE XIV

Summary of Post Test Questionnaire Responses (Continued)

6. How would you rate the quality of simulation in this experiment?

	Excellent	Good	Fair	Poor
Flight	0	5	0	0
Visual	1	2	2	0

Suggestions: Add color; cockpit motion; modernize cockpit; late model transport cockpit.

7. Was simulation of strobe lighting representative of actual conditions?

Excellent	Good	Fair	Poor
1	1	3	0

Comment: Impossible to get as much diffusion as real life conditions.

8. What advantages, if any, do you feel strobe lighting provides?

Subject	
1	It is attention gathering, thus helping in earlier pick up of lights. Also, it helps to point the direction to the runway.
2	Earlier recognition of runway centerline extension.
3	Direction and clarity under adverse conditions but only with additional side lights for reference.
4	Seemed to pick up the lights at a higher altitude.
5	Early recognition and guidance.

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TABLE XIV

Summary of Post Test Questionnaire Responses (Continued)

9. What disadvantages, if any, do you feel strobe lighting causes?

Subject	
1	By itself, strobe lighting does not provide enough clues to permit visual flight.
2	None.
3	None.
4	None.
5	Brilliance; strobes are unnecessary after acquiring or aligned on the system.

categories were strongly affected except for roll and attitude with strobes alone (Question 4). Strobes alone had little guidance value, in the judgment of two of the subjects (Question 9). This reaction was expected because the "strobes only" configuration was introduced only to increase the sensitivity of the experiment and not to represent an alternative for serious operational consideration.

As to the quality of simulation, the flight duplicator received a more favorable reaction than it has on some occasions, and the visual simulation was regarded as fair to excellent (Questions 6 and 7 in Table XIV).

SUMMARY AND CONCLUSIONS

Three experiments have been conducted to determine the modification of the present standard Configuration A Approach Lighting System, if any, required to meet Category II visibility operating requirements. Experiment I explored the gains or losses in guidance value of the basic center row configuration when reduced to a center row of lights extending the centerline and elaborated through five successive increments in complexity, ranging from the 1,000-foot crossbar to side rows and an additional crossbar half way to the runway threshold. Each step in the six levels of complexity considered added a single major element to the pattern and posed the question, does this added element significantly or importantly improve the guidance value of the system. Since performance results failed to discriminate between levels of pattern complexity, it was decided on the basis of operational practicality, pilot acceptance, and a logical analysis of guidance elements to base further configurational studies on the "basic crossbar and center row" configuration illustrated in Figure 2.

Experiment II was conducted to determine whether with proper training the pilots could efficiently and reliably accomplish visual transition with the basic center row and crossbar configuration. The major findings were that displacement recognition posed no problem to the participants at any point in the 40 training trial series; execution of the corrective maneuver, however, required training to overcome an initial pronounced deficiency. Although development of skill in handling the P-3 flight simulator undoubtedly contributed to this effect, growth in ability to utilize the visual display in the performance of the visual compensatory tracking task is felt to have been the major factor. Quite acceptable levels of performance were achieved by all subjects before the termination of the training program, suggesting that this basic configuration was a reasonable point of departure for further development. It is important to note that the configuration does not employ color and appears not to require extra side rows or crossbars to fulfill its functions.

The final question to which this series of experiments was addressed was the guidance value of sequence flashing lights (Experiment III). Do these lights, so popular because of their animated character and attention getting value, add to or degrade the over-all effectiveness of the system? A detailed analysis and experimental study of this question led to the conclusion that sequence flashing lights do indeed increase the detection range of the approach lighting system without

significant deleterious effects on the visual guidance properties of the steady burning lighting array. Compensatory tracking performance was not adversely affected. The popular notion that sequence flashing lights improve lateral alignment, however, was not confirmed, and there was a tendency for them to cause the pilots to level off high and extend their glide.

RECOMMENDATIONS

It is recommended that in the further development and testing of design criteria for Category II approach lighting, consideration be given to the possibility that the modified U. S. National Standard Configuration A herein referred to as the Basic Crossbar and Center Row System, might be an adequate point of departure. It is suggested, also, that sequence flashing lights be regarded as an integral component of the system, although operational procedures ought to be devised wherein the flashers are turned off at the point where the pilot has acquired the steady burning lights and made his commitment to land. Termination of the strobe light installation at the decision bar (1, 000 feet from threshold) would accomplish this purpose reasonably well without denying their use to the pilot next in the landing sequence.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the diligence, effectiveness, and extra effort of Mr. Warren G. Crook, who was the principal experimenter; Mr. Harry M. Halvorsen and Mr. Elmer Haynack for maintenance of the simulation equipments; Mr. Arthur Madge and Mr. John Hughes for assistance in data collection and pilot familiarization; and Mrs. Carol Mangold, Mrs. Jessie Bellino, Mrs. Alice Buck, and Mrs. Helen Tapken for their assistance in the data reduction without which timely completion could not have been accomplished.

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APPENDIX A

EQUIPMENT

The simulation equipment for this experiment consisted of the Curtiss-Wright P-3 Flight Simulator and the Dalto Moving Belt Visual Attachment (Figures 11, 12, and 13).

P-3 Simulator. The Curtiss-Wright P-3A Flight Duplicator provides the pilot with a simplified cockpit (single pilot) environment having standard flight instruments, flight controls and navigation aids. The dynamic flight and response characteristics simulated by the P-3 approximate those of a 25,000-pound, twin engine, B-25 class aircraft. The inputs to the simulator (movements of flight controls, engine controls, etc.) reflect changes in the analogue computers and associated electromechanical devices which, in turn, transform and transmit, to the cockpit, appropriate instrument readings and control forces.

The outputs of the simulator—altitude, heading, airspeed, etc.—control the actions of the Dalto visual simulator attachment.

Dalto Visual Simulator Attachment. The visual attachment provides a visual stimulus representative of such cues as are perceived by the pilot in a visual landing situation under low ceiling, low visibility conditions. The components of the attachment are:

1. Main Dalto unit
2. Television projector
3. Projection screen
4. Interconnecting compatibility unit
5. Experimenter's console.

The main Dalto unit houses an endless, moving neoprene belt, television camera, and a translucent filter screen. A model runway and approach lighting system, scaled 300 to 1, is portrayed on the endless belt. The simulated runway and approach lighting system is achieved by the placement of fluorescent paint "lights" on the belt in the desired pattern and is activated by overhead ultraviolet lamps. The model is representative of 3,000 feet of approach lights and 7,000 feet of runway. The belt is servo-driven at a speed that is proportional to the ground speed of the simulator.

A television camera views the model approach lights and runway system, and this unprogrammed scene or presentation is projected on to a 9 foot by 12 foot screen located approximately 14 feet from the

Figure 11. PROJECTION OF VISUAL SCENE

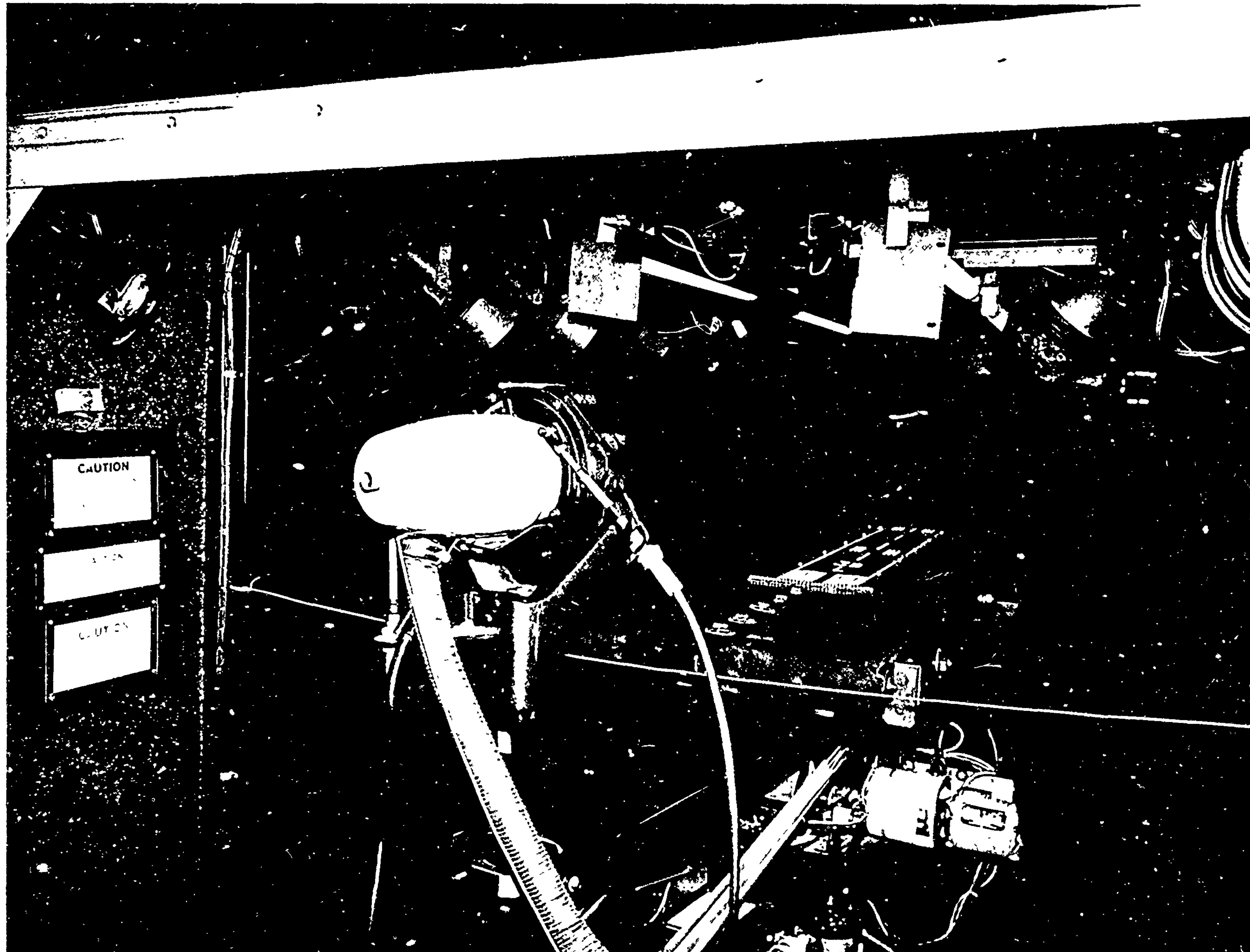

Figure 12. DALTO VISUAL ATTACHMENT: SEGMENT OF MODEL RUNWAY AND APPROACH LIGHTING SYSTEM

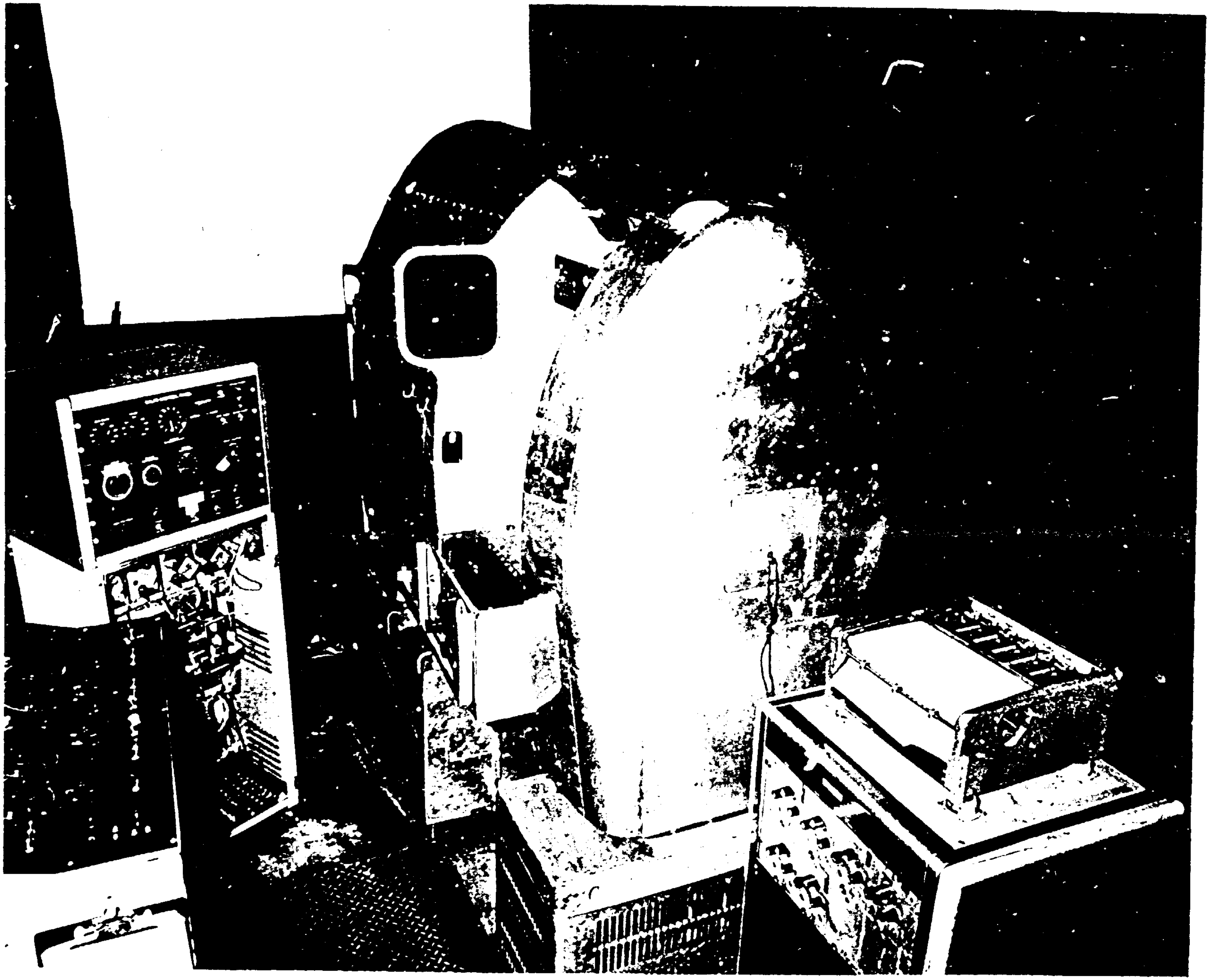

Figure 13. P-3 FLIGHT SIMULATOR COCKPIT, EXPERIMENTER'S CONSOLES, PROJECTION SCREEN AND RECORDER

pilot's eye position. The camera moves in five degrees of freedom—pitch, roll, heading, transverse, and vertical—and its actions are initiated and are synchronous with the movement of the simulator flight instruments and control system through a compatibility unit which matches the outputs of the simulator to the visual attachment. The camera, viewing the moving belt, provides the pilot with the illusion of relative motion towards the approach lights and runway as they would appear during the low visibility approach.

A translucent screen can be moved electrically by the experimenter fore and aft over the simulated runway to increase or decrease the visual range, which is variable from 300 to 2, 600 feet.

The experimenter's console contains the main power switches and controls for starting a flight as well as the controls for setting the desired visual range, ceiling height, and ambient lighting. Ceiling height is obtained by cutting in the camera video at a pre-set altitude, adjustable by the experimenter in 50-foot increments from zero to 400 feet. The ambient lighting condition can be selected as dawn or night by varying the brightness-contrast relationship in the television circuitry.

Night conditions were simulated for the experiment. The visual cues perceived by the pilot were interpreted in terms of the lighting patterns. Additional cues of buildings, terrain, horizon, etc., were not simulated for these low visibility conditions.

The 6-channel Brush Pen Recorder, Model RD 2361, activated prior to reaching an altitude of 300 feet, and operated at a speed of 10 mm/sec., was used to record the following:

<u>Experiment I</u>

Channel 1. Displacements from ILS Localizer; $\pm$ 20 mm. equivalent to 1.25° displacement from localizer centerline (1 dot deflection on the pilot's ILS indicator).

Channel 2. a. Deviations from ILS Glide Slope; $\pm$ 20 mm. equivalent to $\pm$ .5° displacement from the glide slope (2 dots deflection on the pilot's ILS indicator).

b. Flag Drop (FD); a record of glide slope intercept on the runway.

Channel 3. Recorded slant range from 3 miles out to threshold.

Channel 4. a. A pen trace of middle marker passage.

b. Point pen trace of aircraft touchdown.

Channel 5. Unassigned.

Channel 6. Reserved.

Also manually recorded by the experimenter were the following event marks:

1. 200-foot altitude marker.
2. 100-foot altitude marker.
3. Pilot transfer from instrument to visual flight.
4. Roll bar passage.
5. Threshold passage.

Experiments II and III

Channel 1. Displacement from the ILS Localizer, $\pm$ 20 mm. representing 1.25^{o} displacement from localizer centerline (1 dot deflection on the pilot's ILS indicator).

Channel 2. a. Displacement from the ILS Glide Slope, $\pm$ 20 mm. representing $\pm$ .5^{o} displacement from glide slope (2 dots deflection on the pilot's ILS indicator).

b. Flag Drop (FD); a record of glide slope intercept on the runway 1,000 feet from threshold.

Channel 3. Altitude, 40 mm. representing camera altitude of 200 to 0 feet.

Channel 4. Recorded automatically: (a) passing the middle marker; (b) the threshold; (c) the 1,000-foot runway mark; and (d) the moment of touchdown.

Channel 5. Recorded: (a) ground speed of the simulator (40 mm. representing 100 to 160 knots); (b) pilots' event marker, activated by the pilot by a switch on his control wheel, indicating when he first saw the approach lights and again when actually going visual to make his final approach and landing; (c)* experimenters event marker, activated when, in the opinion of the experimenter, the pilot had completed the maneuver correction.

*Not recorded in Experiment II.

Channel 6. Event marker, operated by the experimenter to indicate (a) when the displacement variable was taken off; (b) when the approach lights first appeared on the screen; (c) when the 1,000-foot roll bar came into view; and (d) when the threshold of the runway appeared visually on the screen.

Sequence Flashing Approach Lights

U. S. National Standard Configuration A sequence flashing (strobe) lights are simulated by the use of miniature neon bulbs placed at the center of each 14-foot bar in the approach lighting system, commencing 200 feet from threshold and extending the length of the 3,000-foot system (See Figure 3). The lights are synchronized electromechanically to discharge or flash successively and a complete cycle is flashed twice each second, appearing as a ball of light moving towards the threshold.

The extremely high intensity of condenser discharge lamps, of course, could not be simulated; however, the light levels obtained were well above those of the steady burning lights in the 14-foot bars.

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APPENDIX B

DISPLACEMENT METHODOLOGY

Displacements were introduced in a counterbalanced order so as to control learning and fatigue effects. The degree of displacement on each axis was nominal, reducing the likelihood of a missed approach. Withdrawal of the condition was initiated just prior to the 1,000-foot crossbar coming into view, thus assuring that the pilot's corrective action would be taken with the last 1,000 feet of approach lights in view.

Heading (H). A 90° crosswind of 15 knots, varied "systematically" from left to right, was introduced as the aircraft passed over the OM on the ILS approach to Runway 36. At this time, while still on instrument flight, the pilot became aware of drift by noting the displacement of the ILS localizer needle and applied appropriate heading corrections as required, usually 7° to 8°. Transition from instrument flight to visual flight was accomplished shortly after passing the MM, the location at which the wind variable was withdrawn, the effect being that of a wind shear at low altitude. By observing the visual scene, he was required to effect a heading change in order to maintain proper alignment with the approach lights and runway for landing.

Roll (R). When the pilot had completed his transition from instrument to visual flight on his ILS approach and had the runway lighting pattern in view, a rough air condition was introduced into the simulator and withdrawn immediately. This, in effect, caused a slight but noticeable rotation about the longitudinal axis of the aircraft, represented by a wing down attitude in the visual scene of about 8° to 12°. Observing visual cues from the approach lighting configuration, the pilot was required to apply a roll correction in the appropriate direction in order to maintain proper alignment with the approach lights and runway for landing.

Pitch (A). As the aircraft passed over the OM on its ILS approach, a "wing ice" condition was introduced into the simulator. In order to maintain the proper airspeed (130 knots) and rate of descent throughout the approach, i.e., to stay on glide slope, an increase in power was required, resulting in a slightly nose-high attitude. When the pilot had completed his transition from instrument flight to visual flight, and just prior to the 1,000 foot crossbar coming into view, the icing condition was withdrawn. By observing the visual scene, he was required to decrease power and make an attitude change (nose down) in order to maintain his glide path and rate of closure to achieve proper position and attitude for flare and landing.

Localizer Displacement (D). The ILS localizer, controlled by the experimenter, could be offset one-half degree either side of the extended centerline of the runway and approach lighting system. The displacement was varied from left and right and was introduced prior to the ILS approach. Flying with reference to the ILS system and with the localizer needle centered, the pilot observed a noticeable displacement from the approach lights after transition from instrument to visual flight. He was required to make the necessary correction, right or left, for proper alignment with visual cues obtained from the approach lights and runway. As in all approaches made, he was asked to land as near the center of the runway as practicable, following procedures consistent with good operating practice, to effect a normal landing.

APPENDIX C

SUMMARY OF ANALYSIS OF VARIANCE
EXPERIMENT I

Source of Variation	SS	df	MS	F	p
Recognition of Response Required					
Between Subjects					
Levels	.579	5	.116	.811	Not signif.
Subjects Within Groups	1.998	24	.143		
Within Subjects					
Axis of Rotation	2.256	2	1.128	7.14	.01
Axes x Levels	1.262	10	.126	.797	Not signif.
Axes x Subjects Within Groups	2.335	28	.158		
Execution of Response Required Before Crossing Runway Threshold					
Between Subjects					
Levels	.404	5	.081	.070	Not signif.
Subjects Within Groups	11.216	24	1.163		
Within Subjects					
Axes	.198	2	.099	.208	Not signif.
Axes x Levels	8.911	10	.891	1.876	.10
Axes x Subjects Within Groups	8.726	28	.475		
Execution of Response Required Before Initiating Flare					
Between Subjects					
Levels	.359	5	.072	.0549	Not signif.
Subjects Within Groups	10.215	24	1.311		
Within Subjects					
Axes	.017	2	.008	.021	Not signif.
Axes x Levels	3.463	10	.346	.901	Not signif.
Axes x Subjects Within Groups	6.799	28	.384		

Source of Variation	SS	df	MS	F	p
Rate of Closure or Flare Path (Good)					
Between Subjects					
Levels	1.903	5	.381	1.124	Not signif.
Subjects Within Groups	6.095	24	.339		
Within Subjects					
Axes	2.419	2	1.210	2.840	.10
Axes x Levels	.305	10	.030	.070	Not signif.
Axes x Subjects Within Groups	6.966	28	.426		
Rate of Closure or Flare Path (High)					
Between Subjects					
Levels	4.322	5	.864	1.551	.25
Subjects Within Groups	7.898	24	.557		
Within Subjects					
Axes	3.707	2	1.854	3.478	.05
Axes x Levels	.263	10	.026	.049	Not signif.
Axes x Subjects Within Groups	8.516	28	.533		
Rate of Closure or Flare Path (Low)					
Between Subjects					
Levels	1.676	5	.335	1.701	.25
Subjects Within Groups	2.432	24	.197		
Within Subjects					
Axes	.223	2	.112	.762	Not signif.
Axes x Levels	.349	10	.035	.238	Not signif.
Axes x Subjects Within Groups	2.404	28	.147		

Source of Variation	SS	df	MS	F	p
Longitudinal Positioning at Touchdown (Good)					
Between Subjects					
Levels	6.163	5	1.233	.986	Not signif.
Subjects Within Groups	14.049	24	1.25		
Within Subjects					
Axes	1.637	2	.818	1.091	Not signif.
Axes x Levels	.823	10	.082	.109	Not signif.
Axes x Subjects Within Groups	12.784	28	.750		
Longitudinal Positioning at Touchdown (Short)					
Between Subjects					
Levels	5.630	5	1.126	1.366	Not signif.
Subjects Within Groups	9.912	24	.824		
Within Subjects					
Axes	2.265	2	1.132	2.112	.25
Axes x Levels	.408	10	.041	.076	Not signif.
Axes x Subjects Within Groups	9.251	28	.536		
Longitudinal Positioning at Touchdown (Long)					
Between Subjects					
Levels	.144	5	.029	.592	Not signif.
Subjects Within Groups	.911	24	.049		
Within Subjects					
Axes	.210	2	.105	1.693	.25
Axes x Levels	.078	10	.008	.129	Not signif.
Axes x Subjects Within Groups	1.038	28	.062		

Source of Variation	SS	df	MS	F	p
Lateral Positioning at Touchdown (Good)					
Between Subjects					
Levels	1.308	5	.262	.346	Not signif.
Subjects Within Groups	8.991	24	.758		
Within Subjects					
Axes	3.477	2	1.739	3.653	.05
Axes x Levels	.887	10	.089	.187	Not signif.
Axes x Subjects Within Groups	8.280	28	.476		
Lateral Positioning at Touchdown (Left)					
Between Subjects					
Levels	.320	5	.064	.853	Not signif.
Subjects Within Groups	1.296	24	.075		
Within Subjects					
Axes	.111	2	.055	.724	Not signif.
Axes x Levels	.321	10	.032	.421	Not signif.
Axes x Subjects Within Groups	1.357	28	.076		
Lateral Positioning at Touchdown (Right)					
Between Subjects					
Levels	.428	5	.086	.551	Not signif.
Subjects Within Groups	2.133	24	.156		
Within Subjects					
Axes	.456	2	.228	1.839	.25
Axes x Levels	.448	10	.045	.363	Not signif.
Axes x Subjects Within Groups	2.122	28	.124		

Source of Variation	SS	df	MS	F	p
Average Distance from Threshold					
Between Subjects					
Levels	3,576,639.000	5	715,327.797	.981	Not signif.
Subjects Within Groups	9,918,632.969	24	729,509.539		
Within Subjects					
Axes	3,117,996.750	2	1,558,998.375	.314	Not signif.
Axes x Levels	288,796.688	10	28,879.669	.058	Not signif.
Axes x Subjects Within Groups	9,217,888.938	28	495,930.352		
Average Error in Lateral Positioning at Touchdown					
Between Subjects					
Levels	1,593.822	5	318.764	1.067	Not signif.
Subjects Within Groups	4,015.466	24	298.653		
Within Subjects					
Axes	2,054.755	2	1,027.378	4.232	.05
Axes x Levels	1,126.578	10	112.658	.464	Not signif.
Axes x Subjects Within Groups	4,057.866	28	242.778		

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APPENDIX D

SUMMARY OF ANALYSIS OF VARIANCE
EXPERIMENT III

Source of Variation	SS	df	MS	F	p
Approach Light Detection Latency					
Axis of Rotation (A)	126.533	2	63.267	-	-
Configuration (C)	2,789.733	2	1,394.867	13.562	.01
Subjects (S)	3,572.133	4	893.033	-	-
A x C	480.533	4	120.133	1.728	.25
A x S	822.800	8	102.850	1.480	.25
C x S	1,428.933	8	178.617	2.570	.10
A x C x S	1,112.133	16	69.508		
Displacement Recognition					
Axis of Displacement (A)	7.139	2	3.570	22.125	.01
Configuration (C)	1.498	2	.749	5.673	.05
Subjects (S)	.344	4	.086	-	-
A x C	1.025	4	.256	2.788	.10
A x S	1.291	8	.161	1.756	.25
C x S	1.056	8	.132	1.436	Not signif.
A x C x S	1.470	16	.092		
Rate of Execution: Time to Complete					
Axis of Displacement (A)	2,045.644	2	1,022.822	3.665	.10
Configuration (C)	848.578	2	424.289	4.914	.05
Subjects (S)	4,228.977	4	1,057.244	-	-
A x C	1,096.622	4	274.156	2.000	.25
A x S	2,232.355	8	279.044	2.036	.25
C x S	690.756	8	86.344	-	-
A x C x S	2,192.710	16	137.044		

Source of Variation	SS	df	MS	F	p
Rate of Execution: Completed Before Roll Bar					
Axis of Displacement (A)	6.390	2	3.195	2.826	.25
Configuration (C)	3.435	2	1.717	19.845	.01
Subjects (S)	3.730	4	.932	-	-
A x C	1.415	4	.354	1.410	Not signif.
A x S	9.046	8	1.131	4.508	.01
C x S	.692	8	.086	-	-
A x C x S	4.013	16	.251		
Rate of Execution: Completed Before Threshold					
Axis of Displacement (A)	2.449	2	1.225	6.469	.05
Configuration (C)	.795	2	.397	2.994	.25
Subjects (S)	.519	4	.130	-	-
A x C	.335	4	.084	-	-
A x S	1.514	8	.189	1.164	Not signif.
C x S	1.062	8	.133	-	-
A x C x S	2.601	16	.163		
Rate of Execution: Completed Before Flare					
Axis of Displacement (A)	.022	2	.011	1.000	Not signif.
Configuration (C)	.022	2	.011	1.000	Not signif.
Subjects (S)	.044	4	.011	-	-
A x C	.044	4	.011	1.000	Not signif.
A x S	.088	8	.011	1.000	Not signif.
C x S	.088	8	.011	1.000	Not signif.
A x C x S	.176	16	.011		

Source of Variation	SS	df	MS	F	p
		Flare Path: Normal			
Axis of Displacement (A)	.777	2	.389	-	-
Configuration (C)	.763	2	.381	1.330	Not signif.
Subjects (S)	3.182	4	.796	-	-
A x C	2.024	4	.506	1.263	Not signif.
A x S	3.111	8	.389	-	-
C x S	2.293	8	.287	-	-
A x C x S	6.410	16	.401		
		Flare Path: Leveled Off High			
Axis of Displacement (A)	3.536	2	1.768	7.440	.05
Configuration (C)	1.650	2	.825	3.557	.10
Subjects (S)	2.521	4	.630	-	-
A x C	2.321	4	.580	4.780	.01
A x S	1.901	8	.238	1.957	.25
C x S	1.856	8	.232	1.911	.25
A x C x S	1.943	16	.121		
		Flare Path: Low			
Axis of Displacement (A)	4.080	2	2.040	5.386	.05
Configuration (C)	.283	2	.141	-	-
Subjects (S)	8.162	4	2.040	-	-
A x C	.641	4	.160	-	-
A x S	3.030	8	.379	1.505	.25
C x S	2.504	8	.313	1.244	Not signif.
A x C x S	4.027	16	.252		

Source of Variation	SS	df	MS	F	p
Lateral Position Good at Touchdown					
Axis of Displacement (A)	.154	2	.077	3.500	.10
Configuration (C)	.022	2	.011	-	-
Subjects (S)	.154	4	.039	-	-
A x C	.242	4	.061	1.294	Not signif.
A x S	.176	8	.022	-	-
C x S	.308	8	.039	-	-
A x C x S	.748	16	.047		
Average Deviation from Centerline at Touchdown					
Axis of Displacement (A)	223.600	2	111.800	3.327	.10
Configuration (C)	96.533	2	48.267	2.988	.10
Subjects (S)	66.089	4	16.522	-	-
A x C	417.867	4	104.467	4.231	.05
A x S	268.844	8	33.606	1.361	Not signif.
C x S	129.244	8	16.156	-	-
A x C x S	395.022	16	24.689		
Distance from Threshold at Touchdown					
Axis of Displacement (A)	2,283,098.813	2	1,141,549.406	6.424	.05
Configuration (C)	40,257.243	2	20,128.621	-	-
Subjects (S)	2,795,941.969	4	698,985.492	-	-
A x C	100,010.063	4	25,002.516	1.270	Not signif.
A x S	1,421,346.500	8	177,668.313	9.021	.01
C x S	420,280.281	8	52,535.035	2.668	.10
A x C x S	315,103.125	16	19,693.945		

APPENDIX E

SUMMARY OF RAW SCORE MEANS ON WHICH Ho WAS REJECTED EXPERIMENT III

a. Approach Light Detection Latencies in Seconds*

Configuration (C) x Subject (S) Interaction

		Configuration			
		S (Sequence Flashing Lights Only)	S+B (Sequence Flashing With Steady Burning Lights)	B (Steady Burning Lights Only)	M
S (Subjects)	1	1.4	1.9	2.6	2.0
	2	.4	.4	2.0	.9
	3	1.1	1.3	2.6	1.7
	4	2.0	2.6	6.2	1.7
	5	2.4	2.8	2.8	2.4
	M	1.5	1.8	3.2	

*Letters correspond to similarly lettered parts of Table X

b. Displacement Recognition: Frequency Correct*

Axis of Displacement (A) x C Interaction

		Configuration			
		S	S+B	B	M
A (Axis of Displacement)	A	3.6	5.2	3.4	4.1
	D	5.4	6.0	5.4	5.6
	R	6.0	6.0	6.0	6.0
	M	5.0	5.7	4.9	

*Based on 6 opportunities under each combination of the variables.

c. Rate of Execution of the Corrective Maneuver

1. Approach time remaining before intercept with ILS reference point at completion of maneuver.

A x C Interaction

		Configuration			
		S	S+B	B	M
A	A	8.1	8.5	9.1	8.6
	D	8.8	11.3	10.3	10.1
	R	8.9	9.1	8.5	8.8
	M	8.6	9.7	9.3	

2. Rate of execution: Corrective maneuver completed before roll bar

Configuration		
S	S+B	B
3.5	3.6	4.6

A x S Interaction

		Axis of Displacement			
		A	D	R	M
S	1	2.0	2.0	4.7	2.9
	2	3.3	5.3	4.0	4.2
	3	2.0	2.0	3.7	2.6
	4	3.3	3.0	5.0	3.8
	5	1.0	5.7	5.3	4.0
	M	2.3	3.6	4.5	

3. Rate of execution: Corrective maneuver completed before threshold

Axis of Displacement		
A	D	R
4.9	5.6	5.9

d. Rate of Closure (Flare Path)

1. Leveled off high

A x C Interaction

A		Configuration			
		S	S+B	B	M
	A	3.2	1.0	.8	1.7
	D	.2	.2	.2	.2
	R	.8	.4	.6	.6
	M	1.4	.5	.5	

2. Rate of closure: Frequency leveled off low

Axis of Displacement

A	D	R
.5	1.4	1.8

e. Lateral Positioning at Touchdown

1. Frequency within touchdown zone lights

Axis of Displacement

A	D	R
5.9	5.8	6.0

2. Average deviation from centerline

A x C Interaction

A		Configuration				
		S	S+B	B	M	M Rounded
	A	24.8	14.8	16.0	18.5	19
	D	19.8	25.4	23.6	22.9	23
	R	19.2	20.8	13.8	17.9	18
	M	21.3	20.3	17.8		
M Rounded		21	20	18		

f. Longitudinal Positioning at Touchdown

Average distance from threshold

A x S Interaction

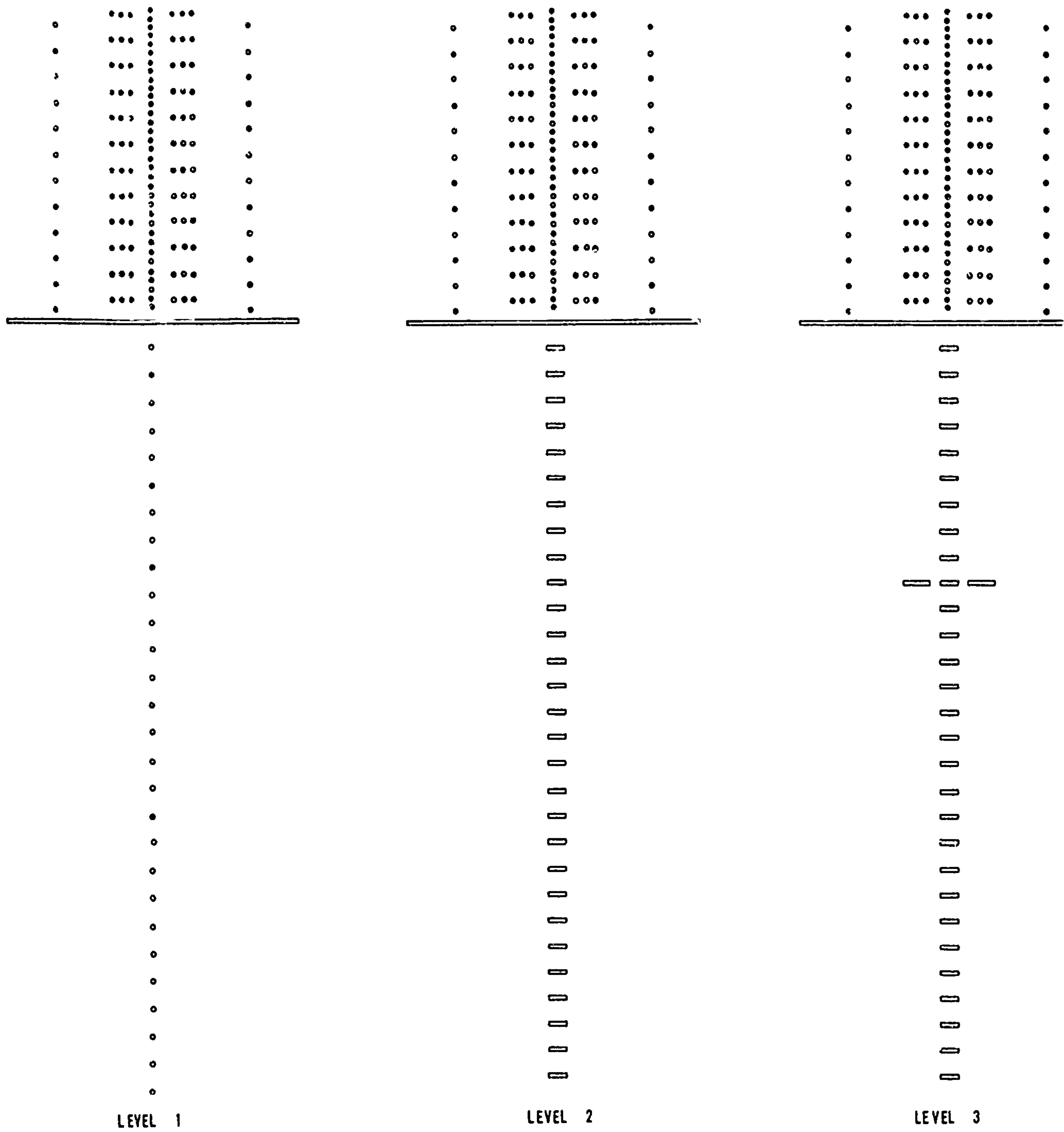
		Axis of Displacement				
		A	D	R	M	M Rounded
S	1	1129	1080	1181	1130	1100
	2	1998	1034	1127	1386	1400
	3	1764	874	975	1204	1200
	4	1848	1761	1709	1773	1800
	5	1998	1516	1449	1654	1700
	M	1747	1253	1288		
	M Rounded	1700	1300	1300		

C x S Interaction

		Configuration				
		S	S+B	B	M	M Rounded
S	1	1075	1224	1091	1130	1100
	2	1611	1213	1335	1386	1400
	3	1277	1139	1198	1205	1200
	4	1731	1825	1762	1773	1800
	5	1587	1823	1553	1654	1700
	M	1456	1445	1388		
	M Rounded	1500	1400	1400		

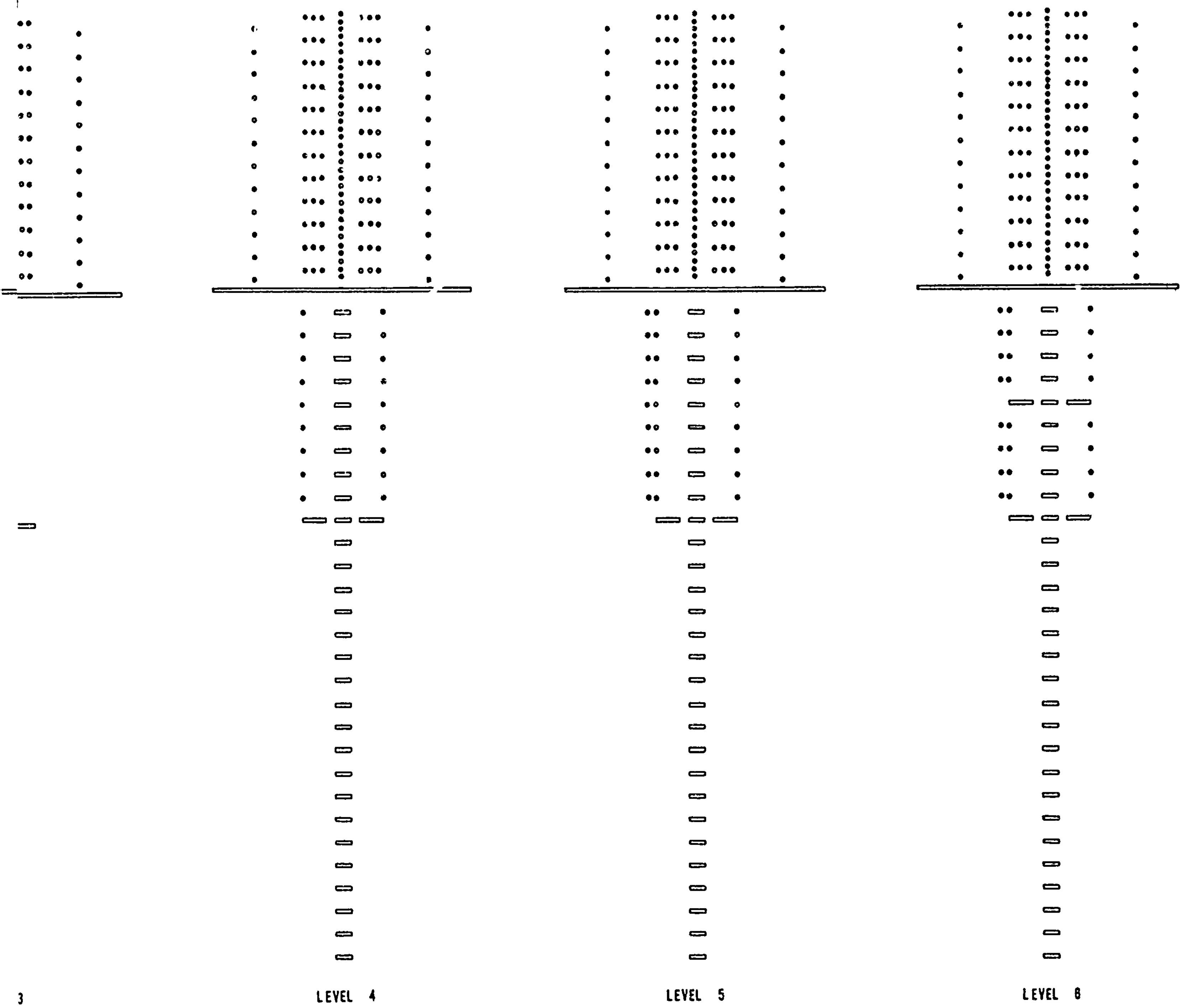
APPENDIX F

CONFIGURATION DRAWINGS



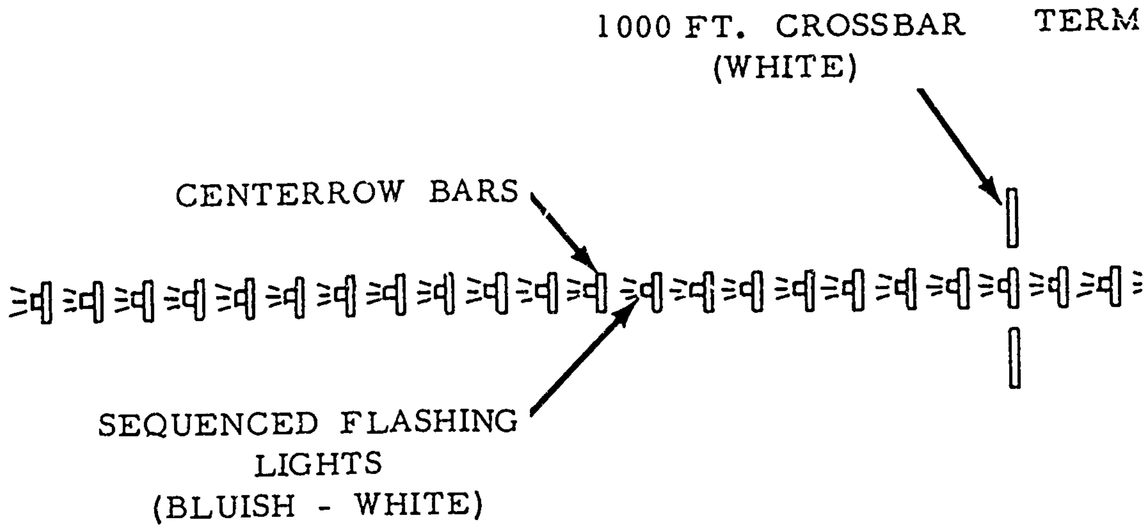
A

Figure 1.

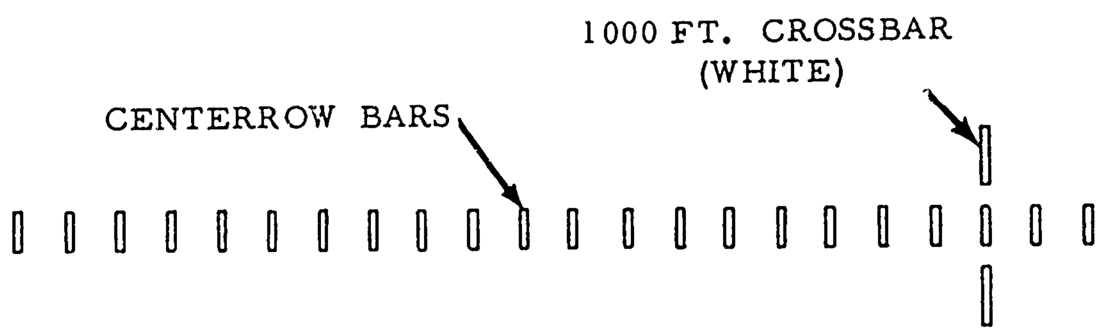


I·e 1. BUILDING BLOCKS APPROACH TO DETERMINATION OF CATEGORY II APPROACH LIGHTING PATTERN REQUIREMENTS.

B



NATIONAL STANDARD "A" APPROACH LIG
CONFIGURATION

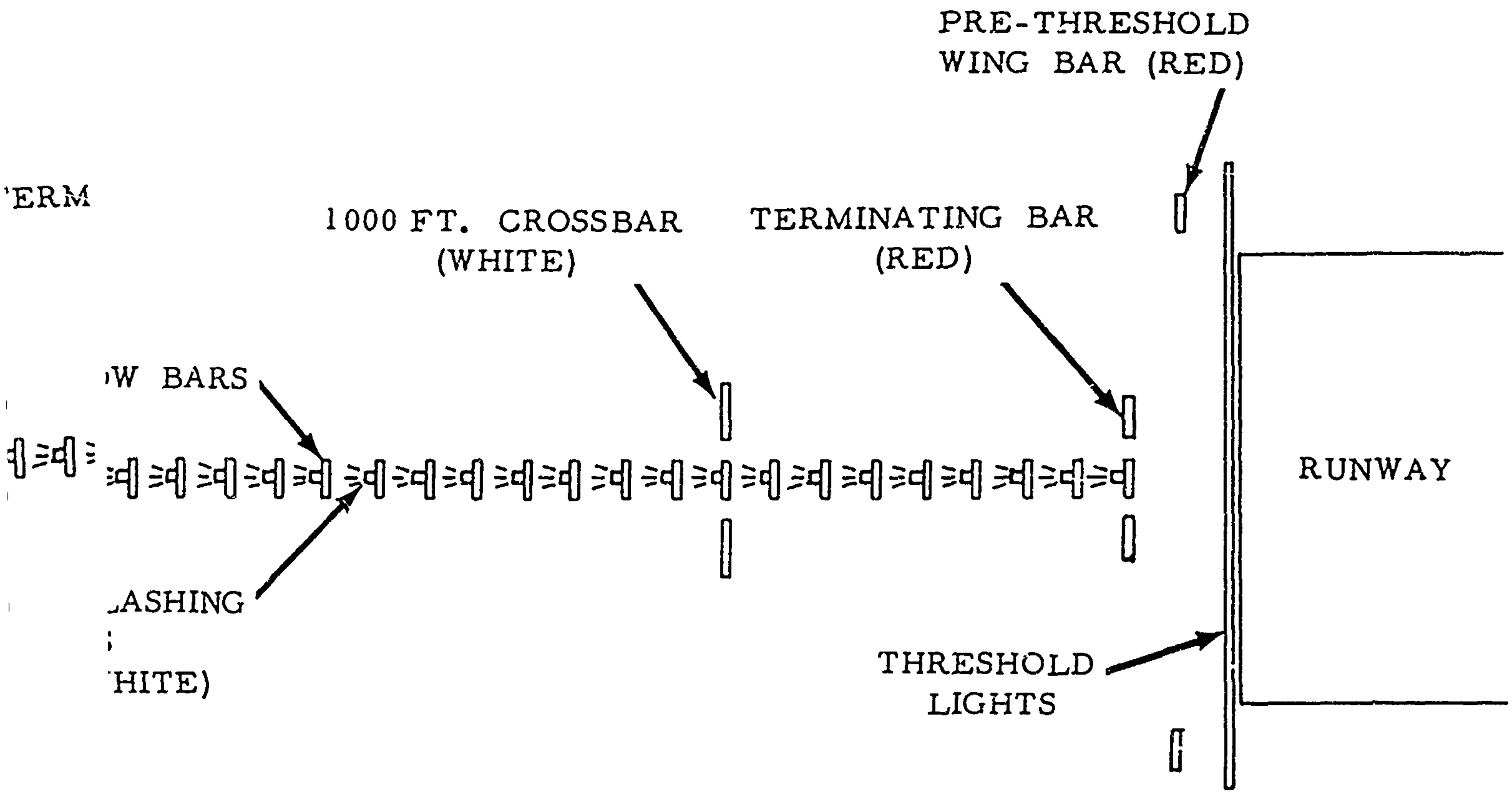


TI

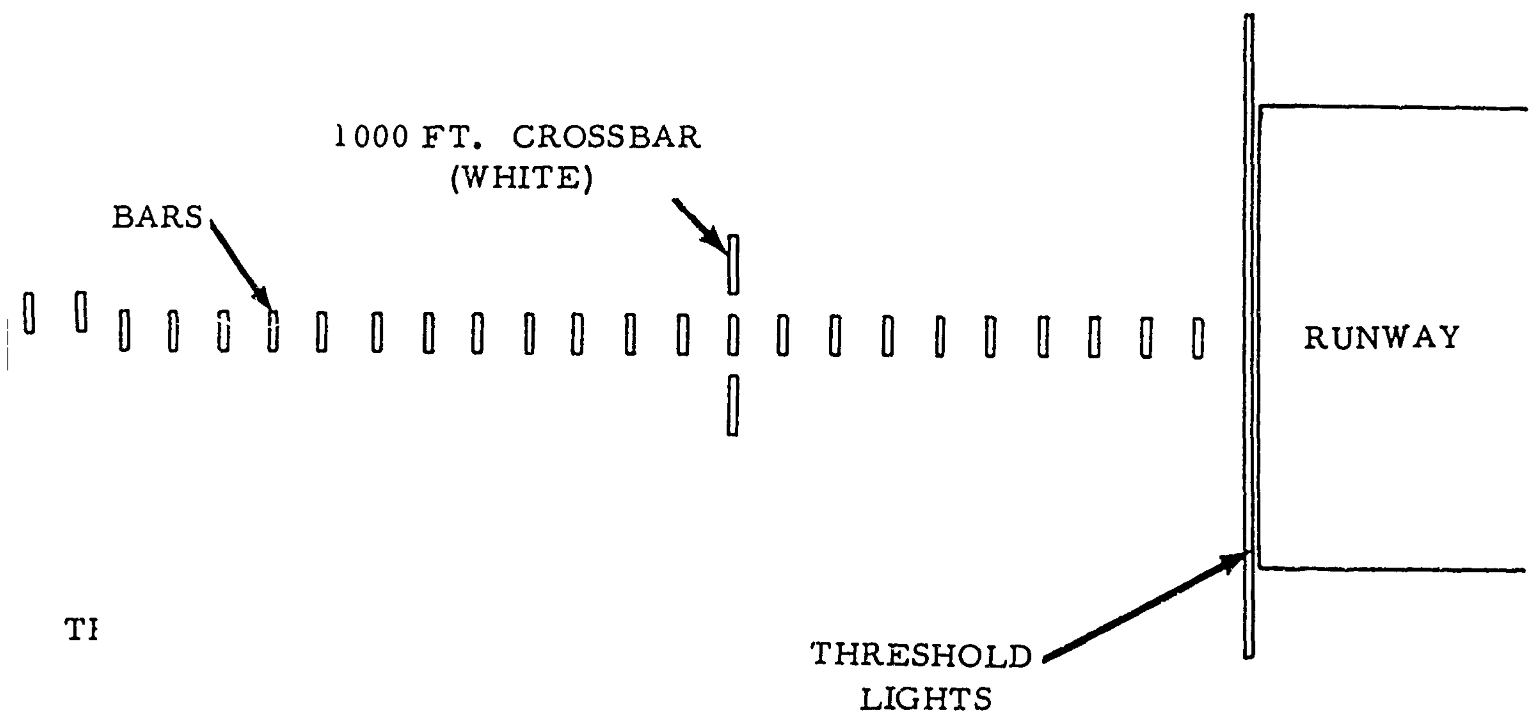
BASIC CENTERROW AND CROSSBAR PATTE

A

Figure 2. BASIC CENTER ROW AND CROSSBAR CONFIGU
CONFIGURATION "A".



ATIONAL STANDARD "A" APPROACH LIGHTING
CONFIGURATION

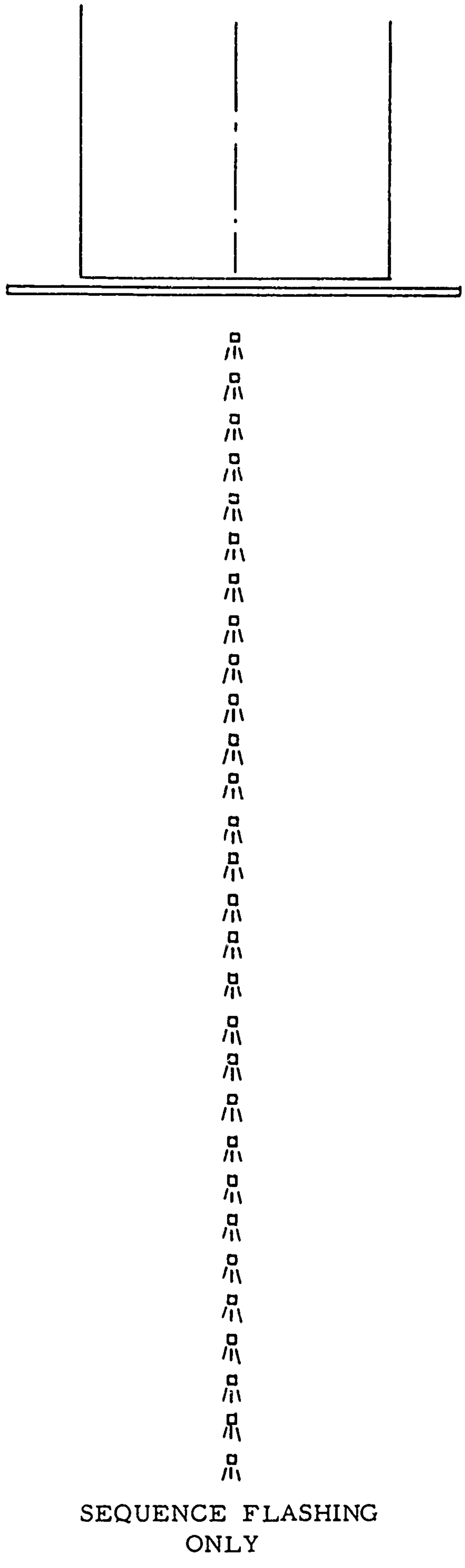


ATTE .C CENTERROW AND CROSSBAR PATTERN

FIGU CENTER ROW AND CROSSBAR CONFIGURATION AND NATIONAL STANDARD

GURATION "A".

B



SEQUENCE FLASHING
ONLY

A

Figure 3.

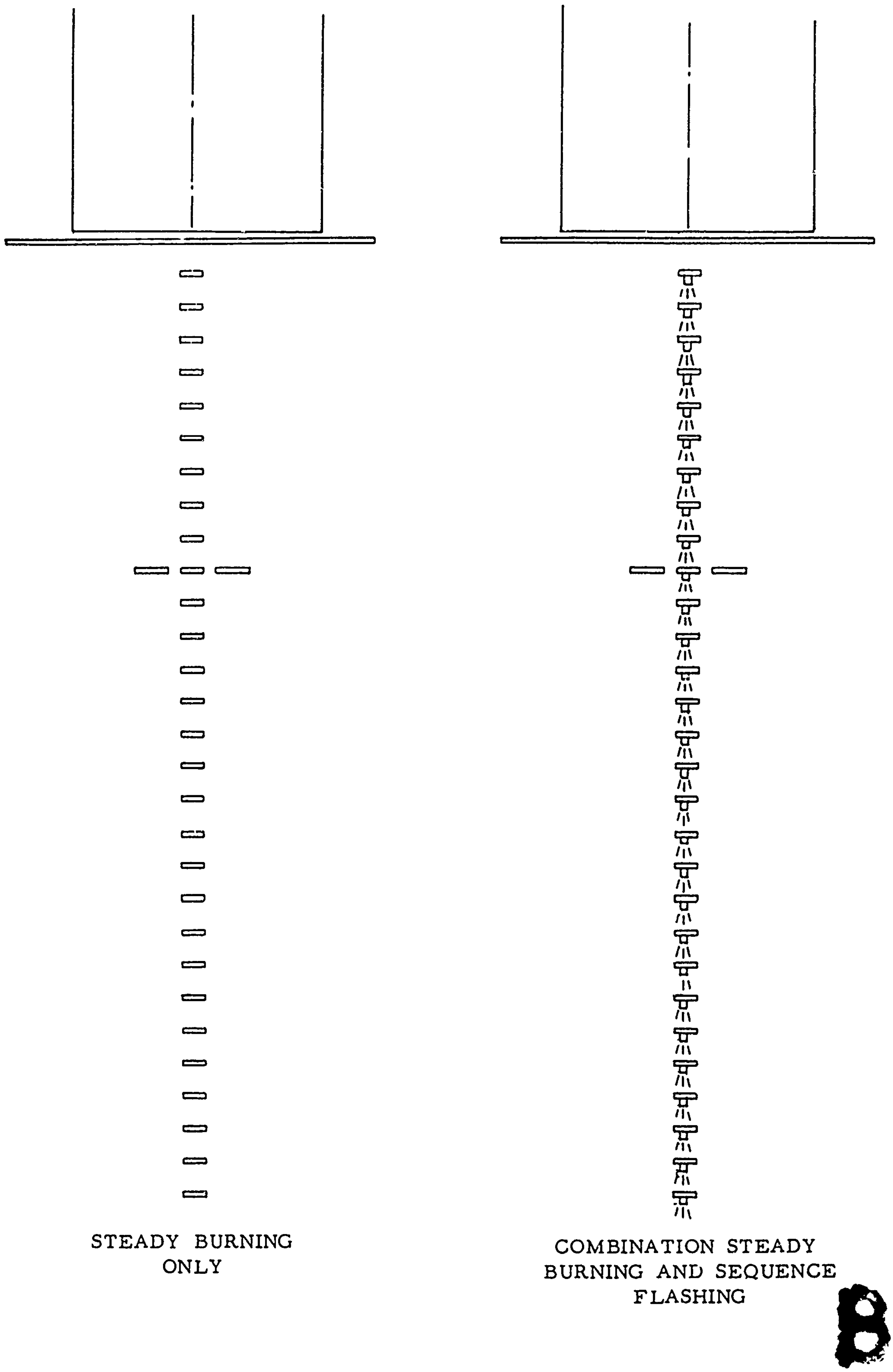


Figure 3. SEQUENCE FLASHING—STEADY BURNING LIGHT COMBINATIONS.

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ANALYSIS OF APPROACH LIGHTING CONFIGURATIONS FOR VISUAL TRANSITION UNDER CATEGORY II OPERATING CONDITIONS by R. McKelvey and G. Brown, Interim Report, Sept. 1964, 84 pp., incl. illus. and append., 16 refs.
(Project No. 430-202-02R, Report No. RD-64-134)

Unclassified Report

Three experiments were conducted to determine requirements for modification of the present U. S. National Standard Approach Lighting System (Configuration A) to meet Category II visibility operating requirements (1,200-foot Runway Visual Range). A building blocks approach was used in which each increment in configuration complexity had to be justified on the basis of a demonstrated gain in performance while the pilot is being systematically exercised in the utilization of the system. The experiments were conducted in a visual

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II. Project No. 430-202-02R
III. Report No. RD-64-134

Descriptors

APPROACH
ALL-WEATHER AVIATION
LANDING AIDS
APPROACH LIGHTS

UNCLASSIFIED

landing simulator. The results indicate that satisfactory performance of visual transition for landing can be achieved with a basic center row and crossbar configuration, including sequence flashing lights operated to the point of acquisition of the steady burning light components of the system.

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